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AFML-TR-74-250
Part III

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DIELECTRIC CONSTANT AND LOSS DATA

LABORATORY FOR INSULATION RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

MAY 1977

TECHNICAL REPORT AFML-74-250, Part III
Interim Report for Period July 1974 - January 1977

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This technical report has been reviewed and is approved.



JOHN C. OLSON
Project Engineer

FOR THE COMMANDER



GARY L. DENMAN, Actg Chief
Laser Hardened Materials Branch
Electromagnetic Materials Division

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21. ABSTRACT (Continue on reverse side if necessary and identify by block number) The main body of this report lists dielectric constant and loss data on materials measured in this laboratory in the period 1 July 1974 through 31 December 1976, together with measurements techniques and calculations. The index following the data section is intended to be a complete reference to dielectric measurement data of this laboratory to date.			

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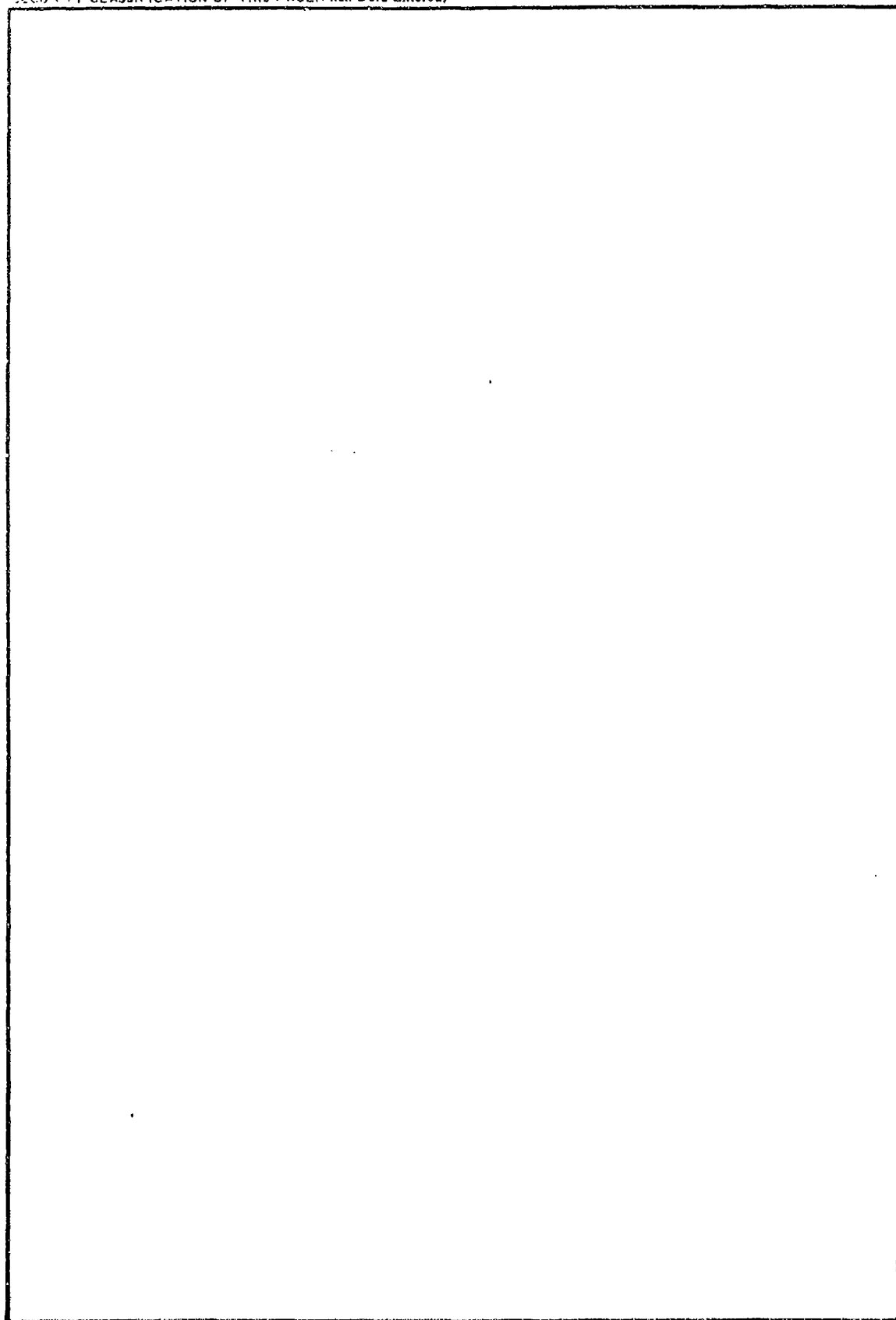
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PREFACE

The dielectric constant and loss data presented in this report were measured at the Laboratory for Insulation Research of the Massachusetts Institute of Technology, Cambridge, Massachusetts, by W. B. Westphal. This work was performed between 1 July 1974 and 31 December 1976 under Contract F33615-75-C-5020, Project No. 7371, Task No. 73710126, for the Air Force Materials Laboratory.

A technical report dated December 1975 presents data on materials measured in the early part of this contract. This final report includes data measured through December 31, 1976. The index following the data section refers to early data reports and uses the prefix 9- for pages of the present report. The data section does not generally include measurements on research samples under development by or for the Air Force Materials Laboratory.

This report was submitted by the author for publication in March 1977.

The work was administered under direction of the AF Materials Laboratory, with Mr. John C. Olson (AFML/LPJ) acting as project engineer.

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MEASUREMENT TECHNIQUES

The basic measurement techniques using bridges, reentrant cavities, standing waves, and dielectric-filled cavities have been discussed in previous reports.* During the present contract period we have used new measurement techniques as follows:

1. The use of large (> 1 -inch diam.) silver-coated cylindrical specimens contained in copper sheath immersed in an oil bath instead of an air oven. Uniform temperature makes possible resolution to better than 0.01% for determination of temperature coefficient of dielectric constant. The absolute accuracy is limited to about 0.1% by uncertainties in the iris correction. Examples of these measurements are shown on pages 12 and 19 of AFML-TR-74-250, Pt. II.

2. The use of a thin coax washer in the center of a dielectric-filled coax sandwich cavity. In the data reported herein for Corning Glasses 7052 and 7056, two coaxial caps of Dynasil 4000 completed the symmetrical package. Losses were measureable through the softening point, but dielectric constant calculations had not been developed at the time of these runs.

3. The use of a thin (< 1 -mm) disk sample to extend the loss range for TE cavities. The data on Nibaxlox in the present report was obtained with this arrangement.

* Tech. Rep. 182, Lab. Ins. Res., Contract AF33(616)-8353, October 1963; Tech. Rep. 201, Lab. Ins. Res., Contract AF33(616)-8353, October 1966; AFML-TR-66-28, Lab. Ins. Res., Contract AF33(615)-2199, January 1966; AF ML-TR-70-138, Lab. Ins. Res., Contract F33615-67C-1612, July 1970. AFML-TR-71-66, Lab. Ins. Res., Contract F33615-70C-1220, April 1971; AFML-TR-74-250, Part II, Lab. Ins. Res., Contract F33615-71-C-1274, December 1975.

4. The use of sandwich cavities with thick samples to increase the loss range. For the sample of AS-3DX-176 of woven silica fibers, the usual pressure welding technique for forming the platinum cavity was not advisable. Instead end caps of Dynasil 4000 were added and the welding done at 1000°C in a drill press instead of the usual hydraulic pressing at 800°C.

5. The use of higher order modes in dielectric-filled cavities to reduce the necessity for very small samples and high wall losses at high frequencies. The Dynasil 4000 measurements at 8.5 GHz with one-inch diameter sample (Pt foil) and at 35 GHz with a 0.4" diam. sample (Pt6-Rh.4 foil) used TE 113 or higher order modes. The length, diameter, and mode are chosen to avoid other resonances within 10% frequency range. This scheme is feasible only with homogeneous isotropic materials.

EQUIPMENT CHANGES

(provided by another contract)

An internal doubler for our Hewlett-Packard Model 8640B signal generator extends the range to 1024 MHz. Commercial crystal controlled multiplier chains have been purchased:

<u>Frequency</u>	<u>Power output</u>
1.686	100 mW
2.45	1 W
3	200 mW
8.515	20 mW
13.6117	315 mW

A tripler for the 13.6 GHz unit provides 150 mW output at 40.8 GHz. Beginning in 1977 no funds are available for equipment purchases from the present source.

FUTURE WORK

Construction of standing-wave equipment for 40 GHz is planned. The sample diameter will be 7/32" nominal. The probe carriage, standing-wave and input plunger section will be water-cooled. Operation to 1500°C should be practical on materials which become at least moderately lossy ($\tan \delta > .002$) at 1200°C. The empty holder loss measurements will include the effects of ionized gases, which have not yet been evaluated.

PROGRAMMING

Program 1 allows us to scan the possibilities for resonance with dielectric-filled cavities using a specified dielectric constant (K1), diameter (D), frequency in GHz (FGHZ), resistivity of the walls relative to copper (RESRA). For each combination of D and K1 the required length (LENGTH) in cm and the wall loss (1/Q for a no-loss dielectric) is calculated.

An integer variable (X) is used to specify the cross section mode according to the following tabulation:

Value of X	Mode	Value of X	Mode
1	TE11	13	TM21
2	21	14	02
3	01	15	31
4	31	101	TM010, L = 0.1 cm
5	41	102	" , L = 3 cm
6	12	103	" , L = 1 cm
7	51	104	" , L = 3 cm
11	TM01		
12	11		

A second integer variable (N) determines the length mode, except for the TM010 mode where four values of length are given in the program.

Program 2 is used for symmetrical sandwich cavities with TE modes. The

thickness of the end disks must be calculated to achieve resonance at the desired frequency. Also, the dilution effect on losses should be calculated so the proper ratio of sample loss to overall loss can be chosen. In Program 2 only the lengths for resonance are calculated; this program will be later expanded to compute overall loss. In the present printout the following are listed:

F	Frequency for resonance in GHz
K1	Dielectric constant of end cap material
TAN1	Loss tangent
K2	Sample dielectric constant
TAN2	Loss tangent of sample
D2	Thickness of sample in cm
D1	Thickness of each end cap for resonance
D1A	Thickness of end cap to form a cavity one wavelength longer

Program 3 is used to compute the properties of the sample when a coaxial wavemeter is used to measure wavelength ($WLM = WL*2$) and width of resonance (DELWL). The program uses iteration to refine initial approximate values of K2 and TAN2 to final values calculated with an accuracy of better than one part in a million.

Program 4 computes the dielectric constant and loss of the sample not centered in a coaxial cavity having wall losses determined by measurement of empty cavity. This is especially useful for measuring low-loss materials to about 1 microradian in the 150 to 500 MHz region.

Program 5 is a modified version of Program 2 of Ref. 6. This is used for calculating the attenuation and phase shift of each layer of a multilayer radome (to 10 layers) with perpendicular incidence and now includes calculation of the overall insertion loss.

Each program is written for FORTRAN G and is listed in the Appendix to this section.

Program 1. Resonant Modes and Losses in Dielectric-Filled Cavities

FORTRAN IV G1 RELEASE 2.0

DATE = 77011

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0001   INTEGER*4 I,II,J,K,L,N,X,ND,NN,NK,NX,M
0002   REAL*8 WL,FGHZ,A,PII,PII2,D,C,K1,Y,B,LENGTH,LEIN,P,NDB,TAMW,
      2SKIND,RESRA,DIA,ONE,TWO,XN,R
0003   DIMENSION DATE(39),K1(10),X(20),D(4),N(5)
0004   NAMELIST/IN/X,D,N,K1,NX,ND,NK,NN,FGHZ,RESRA/OUT/FGHZ,RESRA,SKIND
0005 200 FORMAT(1X,39A2)
0006 201 FORMAT(1H0,10X,39A2,/)
0007 100 FORMAT(2X,2X,1HX,2X,1HN,JX,8HDIA., 4X,4X,3H1/Q,8X,9HLENGTH CM,
      25X,11HLENGTH INCH,4X,1HK)
0008 101 FORMAT(1X,I4,1X,I2,1X,F9.4,1X,F12.9,1X,
      2F12.5,1X,F12.5,1X,F10.5)
0009 77 READ(5,200,END=88) DATE
0010   WRITE(6,201) DATE
0011   READ(5,IN)
0012   WRITE(6,100)
0013   PII=3.141592653600
0014   PII2=2.D0*PII
0015   ONE=1.00
0016   TWO=2.D0
0017   WL=2.99792456201/FGHZ
0018   SKIND=ONE/(PII2*QSORT(FGHZ*5.73505*ONE/RESRA))
0019   M=0
0020   DO 10 I=1,NX
0021   IF(X(I).EQ.1) GO TO 21
0022   IF(X(I).EQ.2) GO TO 31
0023   IF(X(I).EQ.3) GO TO 41
0024   IF(X(I).EQ.4) GO TO 51
0025   IF(X(I).EQ.5) GO TO 51
0026   IF(X(I).EQ.6) GO TO 71
0027   IF(X(I).EQ.7) GO TO 81
0028   IF(X(I).EQ.11) GO TO 121
0029   IF(X(I).EQ.12) GO TO 122
0030   IF(X(I).EQ.13) GO TO 123
0031   IF(X(I).EQ.14) GO TO 124
0032   IF(X(I).EQ.15) GO TO 125
0033   IF(X(I).EQ.101) GO TO 301
0034   IF(X(I).EQ.102) GO TO 302
0035   IF(X(I).EQ.103) GO TO 303
0036   IF(X(I).EQ.104) GO TO 304
0037 10 CONTINUE
0038   WRITE(6,OUT)
0039   GO TO 77
0040 21 Y=1.84118400
0041   XN=ONE
0042   GO TO 80
0043 31 Y=3.05423700
0044   XN=TWO
0045   GO TO 80
0046 41 Y=3.83170600
0047   XN=9.00
0048   GO TO 80
0049 51 Y=4.20118900
0050   XN=4.00
0051   GO TO 80
0052 61 Y=5.31755300
0053   XN=4.00
0054   GO TO 80
0055 71 Y=5.33144300
0056   XN=ONE
0057   GO TO 80
0058 81 Y=6.41561600
0059   XN=5.00
0060   GO TO 80

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Program 1 (cont.)

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0061 121 Y=2.40482600
0062      GO TO 91
0063 122 Y=8.83170600
0064      GO TO 91
0065 123 Y=5.13562200
0066      GO TO 91
0067 124 Y=5.52007800
0068      GO TO 91
0069 125 Y=6.38016200
0070      GO TO 91
0071 301 LENGTH=0.100
0072      GO TO 82
0073 302 LENGTH=0.300
0074      GO TO 82
0075 303 LENGTH=1.00
0076      GO TO 82
0077 304 LENGTH=3.00
0078      GO TO 82
0079 80 DO 12 K=1,N0
0080      A=Y/(PII*D(K))
0081      DO 16 I1=1,NK
0082      C=K1(I1)/WL**2
0083      B=C-A**2
0084      IF (R.LE.1.D-2) GO TO 16
0085      DO 14 L=1,NM
0086      NDB=N(L)
0087      LENGTH=0.500*NDB/DSQRT(B)
0088      LEIN=LENGTH/2.5400
0089      P=NDB*PII/TWO
0090      R=D(K)/LENGTH
0091      TANW=(SKIND/WL)*PII/2*(Y**2*(P**2)*R**3*(ONE-R*(P*D*XN/Y)**2))/
2*((ONE-(XN/Y)**2)*(Y**2*(P*R)**2)**1.5)
0092      DIA=D(K)
0093      WRITE(6,101) X(I),N(L),DIA,TANW,LENGTH,LEIN,K1(I1)
0094 14 CONTINUE
0095 16 CONTINUE
0096 12 CONTINUE
0097      GO TO 10
0098 91 DO 11 K=1,N0
0099      A=Y/(PII*D(K))
0100      DO 17 I1=1,NK
0101      C=K1(I1)/WL**2
0102      B=C-A**2
0103      IF (R.LE.1.D-2) GO TO 17
0104      DO 13 L=1,NM
0105      NDB=N(L)
0106      LENGTH=0.500*NDB/DSQRT(B)
0107      LEIN=LENGTH/2.5400
0108      P=NDB*PII/TWO
0109      R=D(K)/LENGTH
0110      TANW=(SKIND/WL)*PII/2*(ONE+R)/DSQRT(Y**2*(P*R)**2)
0111      DIA=D(K)
0112      WRITE(6,101) X(I),N(L),DIA,TANW,LENGTH,LEIN,K1(I1)
0113 13 CONTINUE
0114 17 CONTINUE
0115 11 CONTINUE
0116      GO TO 10
0117 82 Y=2.40482600
0118      LEIN=LENGTH/2.5400
0119      DO 18 I1=1,NK
0120      DIA=WL*Y/(PII*DSQRT(K1(I1)))
0121      R=DIA/LENGTH
0122      TANW=(SKIND/WL)*PII*(TWO*R)/Y
0123      WRITE(6,101) X(I),N(L),DIA,TANW,LENGTH,LEIN,K1(I1)
0124 18 CONTINUE
0125      GO TO 10
0126 88 CALL EXIT
0127      END

```

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Program 1 (cont.)

Print-Out of the Program

8.5GHZ TE111 TO TE513, TM011 TO TM313, TM010*4L K=3.82, 2.88

X	N	DIA., CM	1/Q	LENGTH CM	LENGTH INCH	K
1	1	2.5400	0.000070775	0.98997	0.38975	3.82200
1	2	2.5400	0.000039988	1.97993	0.77950	3.82200
1	3	2.5400	0.000029725	2.96990	1.16925	3.82200
1	1	2.5400	0.000069444	1.18147	0.46515	2.88000
1	2	2.5400	0.000041754	2.36294	0.93029	2.88000
1	3	2.5400	0.000032525	3.54441	1.39544	2.88000
1	1	1.2700	0.000087678	1.61900	0.63740	3.82200
1	2	1.2700	0.000080639	3.23800	1.27480	3.82200
1	3	1.2700	0.000078293	4.85701	1.91221	3.82200
1	1	1.2700	0.000114491	3.59133	1.41391	2.88000
1	2	1.2700	0.000113505	7.18266	2.82782	2.88000
1	3	1.2700	0.000113177	10.77398	4.24173	2.88000
2	1	2.5400	0.000057830	1.24291	0.48933	3.82200
2	2	2.5400	0.000042273	2.48581	0.97867	3.82200
2	3	2.5400	0.000037087	3.72872	1.46800	3.82200
2	1	2.5400	0.000059218	1.70660	0.67189	2.88000
2	2	2.5400	0.000050030	3.41319	1.34378	2.88000
2	3	2.5400	0.000046968	5.11979	2.01566	2.88000
3	1	2.5400	0.000033532	1.79311	0.70595	3.82200
3	2	2.5400	0.000028351	3.58623	1.41190	3.82200
3	3	2.5400	0.000026624	5.37934	2.11785	3.82200
4	1	2.5400	0.000297386	2.83332	1.11548	3.82200
4	2	2.5400	0.000296073	5.66664	2.23096	3.82200
4	3	2.5400	0.000295635	8.49996	3.34644	3.82200
5	1	2.5400	0.000297386	2.83332	1.11548	3.82200
5	2	2.5400	0.000296073	5.66664	2.23096	3.82200
5	3	2.5400	0.000295635	8.49996	3.34644	3.82200
11	1	2.5400	0.000097732	1.07209	0.42208	3.82200
11	2	2.5400	0.000063370	2.14419	0.84417	3.82200
11	3	2.5400	0.000051916	3.21628	1.25625	3.82200
11	1	2.5400	0.000097276	1.32914	0.52328	2.88000
11	2	2.5400	0.000065346	2.65828	1.04657	2.88000
11	3	2.5400	0.000054703	3.98741	1.56985	2.88000
101	0	1.3786	0.000421843	0.10000	0.03937	3.82200
101	0	1.5881	0.000477836	0.10000	0.03937	2.88000
102	0	1.3786	0.000176246	0.30000	0.11811	3.82200
102	0	1.5881	0.000194910	0.30000	0.11811	2.88000
103	0	1.3786	0.000090286	1.00000	0.39370	3.82200
103	0	1.5881	0.000095886	1.00000	0.39370	2.88000
104	0	1.3786	0.000065727	3.00000	1.18110	3.82200
104	0	1.5881	0.000067593	3.00000	1.18110	2.88000

600T

FGHZ= 8.514999999999999 , FESSA= 1.000000000000000

SKIND= .7202132291136459940-04

6END

Program 2. Resonant Lengths of Three-Layer Symmetrical TE Cavities

```

0001     INTEGER *2 I,J,K,N,KOUNT
0002     REAL*8 PII,ONE,WLC,FR,FG,K2,K2G,K1,K1G,D2,D2G,D1G,TAN1,TAN1G,D1,
      2TAN2,TAN2G,DIA,WL,U,B1,T1,B2,T2,R1,R,ERROR,WE,EROLD,D1OLD,BD,BDA,
      2STEP(14)/1,D-1,1,D-2,3,D-3,1,D-3,3,D-4,1,D-4,3,D-5,1,D-5,3,D-6,
      3,D-6,3,D-7,1,D-7,3,D-8,1,D-8/F(2)/1,D0,-1,D0/DIA,PII2
0003     DIMENSION DATE(39),FG(8),K1G(8),K2G(8),TAN1G(8),TAN2G(8),D2G(8)
0004     NAMELIST/IN/FG,K1G,K2G,TAN1G,TAN2G,D2G,DIA,N/OUT/WL,U,B1,T1,
      2B2,T2,R,ERROR/OUT1/D1,T1,R1,R,ERROR
0005 200 FORMAT(1X,39A2)
0006 201 FORMAT(11H0,20X,39A2,F)
0007 100 FORMAT(4X,1HF,7X,2HK1,6X,2HK2,7X,4HTAN1,6X,4HTAN2,7X,2HD2,7X,2HD1,
      28X,3HD1A,4X,4HD1D1,3X,7HTANB2D2,4X,2H11,4X,5HERROR)
0008 101 FORMAT(1X,F7.3,1X,F7.3,1X,F7.3,1X,F9.5,1X,F9.5,1X,F8.4,1X,F8.4,
      21X,F9.4,1X,F8.4,1X,F8.4,1X,F7.4,1X,E9.4)
0009 77 READ(5,200,END=88) DATE
0010 WRITE(6,201) DATE
0011 READ(5,IN)
0012 WRITE(6,100)
0013 PII=3.1415926536D0
0014 PII2=2.00*PII
0015 ONE=1.00
0016 WLC=1.706293D0*DIA
0017 DO 10 I=1,N
0018 FR=FG(I)
0019 K2=K2G(I)
0020 K1=K1G(I)
0021 D2=D2G(I)
0022 TAN1=TAN1G(I)
0023 TAN2=TAN2G(I)
0024 WL=2.99792456201/FR
0025 U=(WL/WLC)**2
0026 B1=PII2*DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2))/2.00)
      2/WL
0027 B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.00)
      2/WL
0028 T2=DTAN(B2*D2)
0029 R=ONE/T2*DSQRT((ONE/T2)**2+ONE)
0030 T1=R*DSQRT(K1/K2)
0031 D1G=DATAN(T1)
0032 D1=D1G/B1
0033 R1=T1*DSQRT(K2/K1)
0034 R=2.00/(R1-ONE/R1)
0035 ERROR=DABS(T2-R)
0036 DO 400 K=1,14
0037 DO 600 J=1,2
0038 420 WE=ONE+STEP(K)*F(J)
0039 KOUNT=0
0040 401 KOUNT=KOUNT+1
0041 IF(KOUNT.GT.50) GO TO 449
0042 EROLD=ERROR
0043 D1OLD=D1
0044 D1=D1*WE
0045 IF(D1.LT.1.D-4) GO TO 449
0046 T1=DTAN(B1*D1)
0047 R1=T1*DSQRT(K2/K1)
0048 R=2.00/(R1-ONE/R1)
0049 ERROR=DABS(T2-R)
0050 IF(ERROR.LE.EROLD) GO TO 401

```

Program 2 (cont.)

```

0051      D1=C1GLD
0052      ERROR=EROLD
0053 600  CONTINUE
0054      IF(ERROR.LE.1.D-6) GO TO 450
0055 400  CONTINUE
0056      GO TO 450
0057 449  WRITE(6,OUT1)
0058 450  BD=B1*D1
0059      BDA=BD*PII
0060      DIA=BDA*WL/(DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))*2)))/
        22.D0)*PII2)
0061      WRITE(6,101) FR,K1,K2,TAN1,TAN2,D2,D1,DIA,BD,T2,T1,ERROR
0062 10  CONTINUE
0063      GO TO 77
0064 8A  CALL EXIT
0065      END

```

Print-Out of the Program

AS3DX 176-17

P	K1	K2	TAN1	TAN2	D2	D1	D1A
6.515	3.823	2.840	0.00015	0.00180	1.9050	0.2219	1.2116
8.600	3.823	2.840	0.00015	0.00180	1.9050	0.2086	1.1866
8.650	3.823	2.840	0.00015	0.00180	1.9050	0.2010	1.1722

B1D1	TANB2D2	T1	ERROR
0.7040	-3.1514	0.7346	.0
0.6701	-2.5596	0.6886	.2220D-15
0.6500	-2.2964	0.6624	.2220D-15

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Program 3. Calculation of Dielectric Properties of Center Section in
Three-Layer Symmetrical Cavity

```

0001  INTEGER*4 I,J,K,N,II,KOUNT,COUNT
0002  REAL*8 WLM,D1,D2,K1,DIA,TAN1,K2I,TEMP,PII,PII2,ONE,SOLD,
      2STEP(14)/1.D-1,1.D-2,3.D-3,1.D-3,3.D-4,1.D-4,3.D-5,1.D-5,3.D-6,
      31.D-6,3.D-7,1.D-7,3.D-8,1.D-8/F(2)/1.D0,-1.D0/WE,K2,TANCAL,
      4T1,B1,WL,A1,U,WLC,K1G,TANIG,32,TANM,Y2,K2OLD,DELWL,ERROR,EROLD,
      5SILLY(2),WL1,TANA,TH1R,TH1I,TAN2,A2,TH2R,TH2I,ZB1R,ZB1I,TOLD
0003  COMPLEX*16 ZONE,ZOONE,ZB1,TWO,A1C,B1C,G1,TH1RC,
      2TH1IC,TH1,A2C,R2C,G2,G12,G2I,TH2RC,TH2IC,TH2
0004  EQUIVALENCE (SILLY(1),ZB1)
0005  DIMENSION DATE(39),WLM(30),TEMP(30),K1G(30),TAN1G(30),
      2DELWL(30)
0006  NAMELIST/IN/WLM,TEMP,D1,D2,K1G,TAN1G,K2I,DELWL,N,DIA/OUT/K2,TAN2,
      2TANCAL,ERROR,ZB1R,ZB1I,KOUNT,X,J/OUT1/WL,U,G1,WL1,TH1,G2,TH2,ZB1
0007 200 FORMAT(1X,39A2)
0008 201 FORMAT(1H0,20X,39A2,/)
0009 100 FORMAT(1X,16H WAVELENGTH MEAS.,2X,12H TEMP. DEG. C,4X,2HK1,5X,
      24HTAN1,8X,5HDELWL,4X,2HD1,7X,2HD2,6X,3HDIA,6X,3HK2I)
0010 101 FORMAT(1X,F9.4,14X,F7.2,1X,F7.3,1X,F9.5,1X,F8.4,1X,F8.4,1X,F8.4,
      1X,F8.4,1X,F8.4)
0011 102 FORMAT(1X,4HTEMP,9X,4HTANM,8X,4HTAN2,9X,2HK2,9X,4HZB1R,11X,4HZB1I,
      28X,5HTANCAL,5X,5HERROR,7X,1HK)
0012 103 FORMAT(1X,F7.2,1X,F12.7,1X,F12.7,1X,F12.4,1X,F12.7,1X,F12.7,1X,
      2F12.7,1X,E13.6,1X,I2)
0013 77 READ(5,200,END=88) DATE
0014 WRITE(6,201) DATE
0015 READ(5 IN)
0016 WRITE(6,100)
0017 DO 8 II=1,N
0018 WRITE(6,101) WLM(II),TEMP(II),K1G(II),TAN1G(II),DELWL(II),D1,
      2D2,DIA,K2I
0019 A CONTINUE
0020 ZONE=(1.D0,0.D0)
0021 ZOONE=(0.D0,1.D0)
0022 PII=3.141592653600
0023 PII2=6.283185307200
0024 ONE=1.D0
0025 TWO=2.D0*ZONE
0026 WLC=1.706255D0*DIA
0027 K2=K2I
0028 WRITE(6,102)
0029 DO 10 I=1,N
0030 WL=WLM(I)/2.D0
0031 U=(WL/WLC)**2
0032 K1=K1G(I)
0033 TANM=DELWL(I)/(3.D0*WL)-3.D-4*DSQRT(ONE+(TEMP(I)-TEMP(1))*3.8D-3)
0034 TAN2=TANM*(2.D0*U1+D2)/D2
0035 TAN1=TAN1G(I)
0036 B1=PII2*DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2)))/2.D0)
      2/WL
0037 A1=PII2*DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2)))/2.D0)
      2/WL
0038 T1=OTAN(B1*D1)
0039 WL1=WL/DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2)))/2.D0)
0040 A1C=ZONE*A1
0041 B1C=ZOONE*B1
0042 G1=A1C*B1C
0043 TANA=DTANM(A1*D1)
0044 TH1R=TANA*(ONE+T1**2)/(ONE+TANA**2*T1**2)
0045 TH1I=T1*(ONE-TANA**2)/(ONE+TANA**2*T1**2)
0046 TH1RC=ZONE*TH1R
0047 TH1IC=ZOONE*TH1I
0048 TH1=TH1RC+TH1IC

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0049      A2=PII2*DSQRT((K2-U)*(-ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2)))/2.00)
          2/WL
0050      B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2)))/2.00)
          2/WL
0051      A2C=ZONE*A2
0052      B2C=ZONE*B2
0053      G2=A2C*B2C
0054      G12=G1/G2
0055      G21=G2/G1
0056      TAHA=DTANH(A2*D2)
0057      T2=DTAN(B2*D2)
0058      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
0059      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
0060      TH2RC=ZONE*TH2R
0061      TH2IC=ZONE*TH2I
0062      TH2=TH2RC+TH2IC
0063      ZB1=(TWO*TH1+G21*TH2*TH1**2+G12*TH2)/(ZONE+(G21+G12)*TH1*TH2+
          2*TH1**2)
0064      ZB1R=SILLY(1)
0065      ZB1I=SILLY(2)
0066      TANCAL=ZB1R*WL1/(PII*(2.00*D1+D2))
0067      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
0068      COUNT=0
0069      440 COUNT=COUNT+1
0070      IF(COUNT GT.3) GO TO 450
0071      DO 400 K=1,14
0072      SOLD=STEP(K)
0073      DO 600 J=1,2
0074      420 WE=ONE+STEP(K)*F(J)
0075      KOUNT=0
0076      401 KOUNT=KOUNT+1
0077      IF(KOUNT GT.90) GO TO 450
0078      IF(KOUNT GT.10.AND.STEP(K).LE.1.0-3) GO TO 411
0079      GO TO 425
0080      411 STEP(K)=STEP(K)*10.00
0081      GO TO 420
0082      425 EROLD=ERROR
0083      K2OLD=K2
0084      K2=K2*WE
0085      B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2)))/2.00)
          2/WL
0086      A2=PII2*DSQRT((K2-U)*(-ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2)))/2.00)
          2/WL
0087      A2C=ZONE*A2
0088      B2C=ZONE*B2
0089      G2=A2C*B2C
0090      G12=G1/G2
0091      G21=G2/G1
0092      TAHA=DTANH(A2*D2)
0093      T2=DTAN(B2*D2)
0094      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
0095      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
0096      TH2RC=ZONE*TH2R
0097      TH2IC=ZONE*TH2I
0098      TH2=TH2RC+TH2IC
0099      ZB1=(TWO*TH1+G21*TH2*TH1**2+G12*TH2)/(ZONE+(G21+G12)*TH1*TH2+
          2*TH1**2)
0100      ZB1R=SILLY(1)
0101      ZB1I=SILLY(2)
0102      TANCAL=ZB1R*WL1/(PII*(2.00*D1+D2))
0103      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
0104      IF(ERROR LE.EROLD) GO TO 401
0105      ERROR=EROLO
0106      K2=K2OLD

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Program 3 (cont.)

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0107 STEP(K)=SOLD
0108 600 CONTINUE
0109 DO 700 J=1,2
0110 421 WE=ONE+STEP(K)*F(J)
0111 KOUNT=0
0112 402 KOUNT=KOUNT+1
0113 IF(KOUNT.GT.90) GO TO 450
0114 IF(KOUNT.GT.10.AND.STEP(K).LE.1.0-3) GO TO 412
0115 GO TO 428
0116 412 STEP(K)=STEP(K)*10.00
0117 GO TO 421
0118 428 TOLD=TAN2
0119 EROL=EROL0
0120 TAN2=TAN2*WE
0121 B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.00)
2/WL
0122 A2=PII2*DSQRT((K2-U)*(-ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.00)
2/WL
0123 A2C=ZONE*A2
0124 B2C=ZONE*B2
0125 G2=A2C+B2C
0126 G12=G1/G2
0127 G21=G2/G1
0128 TANA=DTANH(A2*D2)
0129 T2=DTAN(B2*D2)
0130 TH2R=TANA*(ONE+T2**2)/(ONE+TANA**2*T2**2)
0131 TH2I=T2*(ONE-TANA**2)/(ONE+TANA**2*T2**2)
0132 TH2RC=ZONE*TH2R
0133 TH2IC=ZONE*TH2I
0134 TH2=TH2RC+TH2IC
0135 ZR1=(TWO*TH1+G21*TH2*TH1**2+G12*TH2)/(ZONE*(G21+G12)*TH1*TH2+
2TH1**2)
0136 ZR1R=SILLY(1)
0137 ZR1I=SILLY(2)
0138 TANCAL=ZR1R*WL1/(PII*(2.00*D1+D2))
0139 ERROR=DSQRT((TANCAL-TANM)**2+ZR1I**2)
0140 IF(ERROR.LE.EROL0) GO TO 402
0141 TAN2=TOLD
0142 ERROR=EROL0
0143 STEP(K)=SOLD
0144 700 CONTINUE
0145 IF(ERROR.LE.1.0-6) GO TO 450
0146 400 CONTINUE
0147 450 WRITE(6,103) TEMP(1),TANM,TAN2,K2,ZR1R,ZR1I,TANCAL,ERROR,K
0148 10 CONTINUE
0149 GO TO 77
0150 84 CALL EXIT
0151 END

```

Print-Out of the Program

AS-3DX 176-17

WAVELENGTH MEAS.	TEMP. DEG. C	K1	TAN1	DELWL
6.9316	25.00	3.823	0.00015	0.0200
		D1	D2	DIA
		1.1722	1.9050	2.5400
		K2	ZR1R	K2I
		2.8639	0.0111582	2.4400
TEMP	TANM	TAN2	ZR1I	TANCAL
25.00	0.0016236	0.0040740	0.0000006	0.0016236
			ERROR	
			0.5834790-06	11

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Program 4. Calculation of Dielectric Properties of Sample in Asymmetric Three-Layer Coaxial Cavity

```

0001  INTEGER*4 I,J,K,N,M,KOUNT,COUNT
0002  REAL*8 FS1,FS2,FS,FE1,FE2,FE,QS,QE,C,WLO,DA,DB,SIGR,A1,B1,TAN1,
      2Q1,MV,D1,D2,D3,DT,K2,K221,TAN2,ONE,TWO,P11,P112,Z1,THRB4,WLOAA,
      3TH1T,RZ,TANCAL,TANM,T1,TAMA,TH1R,TH1I,A2,B2,TH2R,TH2I,T3,TH3R,
      4TH3I,ZB1R,ZB1I,ERROR,SOLD,EROLD,K2OLD,WE,TOLD,T2,SILLY(2),DRB,DQ,
      2STEP(14)/1.0-1,1.0-2,3.0-3,1.0-3,3.0-4,1.0-4,3.0-5,1.0-5,3.0-6,
      31.0-6,3.0-7,1.0-7,3.0-8,1.0-8/,F(2)/1.00,-1.00/,EXP1,EXPE
0003  COMPLEX*16 ZONE,ZOONE,TWOC,Z1R,Z1I,Z1C,THRB4C,TH1TC,Z5C,ZR1,
      2A1C,B1C,G1,TH1RC,TH1IC,TH1,A2C,B2C,G2,G12,G21,TH2RC,TH2IC,TH2,
      3TH3RC,TH3IC,TH3,THRB3,THRB2,ZB5
0004  EQUIVALENCE (SILLY(1),7R1)
0005  DIMENSION FE1(10),FE2(10),FS1(10),FS2(10),D1(10),TH(10),
      2DATE(39),M(10),DQ(10)
0006  NAMELIST/CONST/DA,DB,SIGR,EXP1,EXPE/IN/FS1,FS2,FE1,FE2,DQ,TH,M,N
0007 200 FORMAT(1X,39A2)
0008 201 FORMAT(/1H0,20X,39A2/)
0009 101 FORMAT(/1H0,2X,15HFREQ. EMPTY MHZ,12X,19HFREQ. SAMPLE-IN MHZ,10X,
      25MDQ-CM,4X,15HSAMPLE THICK CM,2X,14HVO. HALF WAVES)
0010 102 FORMAT(1H ,F12.6,1X,F12.6,2X,F12.6,1X,F12.6,1X,F12.5,2X,
      2F12.5,12X,12)
0011 104 FORMAT(/1H0,1X,7HQ-EMPTY,5X,11HQ-THEO.WALL,3X,13HQ-WITH SAMPLE,3X,
      29HDI=CONST,3X,12HLOSS TANGENT)
0012 105 FORMAT(1H ,F10.4,4X,F10.4,5X,F10.4,2X,F10.5,4X,F12.8)
0013 106 FORMAT(1H0,1X,27HEND LOSS MULTIPLYING FACTOR,1X,
      218HWALL LOSS EXPONENT,1X,17HEND LOSS EXPONENT)
0014 107 FORMAT(1H ,8X,F12.6,8X,F12.6,8X,F12.6)
0015 108 FORMAT(1H0,6X,6HTANCAL,8X,4HTANM,8X,10HCAVITY LENGTH-CM,10X,
      28HEND LOSS)
0016 109 FORMAT(1H ,2X,F12.8,2X,F12.8,4X,F12.5,6X,1H(,E12.6,6X,E12.6,1H))
0017 112 FORMAT(1H0,6X,4HTANM,11X,4HTAN2,7X,9HUIE=CONST,8X,6HZ,REAL,8X,
      27HZ-IMAG.,11X,4HTAN1,6X,5HERROR,10X,1HX)
0018 113 FORMAT(1H ,2X,F12.8,2X,F12.8,2X,F10.5,9X,E12.6,2X,E12.6,2X,F12.8,
      22X,E12.6,2X,12)
0019 77 READ(5,200,FNO=88) DATE
0020 WRITE(6,201) DATE
0021 READ(5,IN)
0022 READ(5,CONST)
0023 WRITE(6,101)
0024 DO 20 I=1,N
0025 D1(I)=2.5400*DQ(I)
0026 D2=2.5400*TH(1)
0027 WRITE(6,102) FE1(1),FE2(1),FS1(1),FS2(1),D1(1),D2,M(1)
0028 20 CONTINUE
0029 ZONE=(1.00,0.00)
0030 ZOONE=(0.00,1.00)
0031 P11=3.141592653600
0032 P112=6.283185307200
0033 ONE=1.00
0034 TWO=2.00
0035 TWOC=ZONE*TWO
0036 DAA=DA*2.5400
0037 DBB=DB*2.5400
0038 C=2.99792456204
0039 DO 10 I=1,N
0040 D2=2.5400*TH(I)
0041 FE=(FE1(I)+FE2(I))/TWO
0042 FS=(FS1(I)+FS2(I))/TWO
0043 QE=FE/(FE1(I)-FE2(I))
0044 QS=FS/(FS1(I)-FS2(I))
0045 A1=3.470-7*DSQRT(FE/SIGR)*(TWO/DAA+TWO/DBB)/DLOG(DBB/DAA)
0046 WLO=C/FE
0047 B1=P112*DSQRT(1.0005400)/WLO
0048 TAN1=TWO*A1*B1/(B1**2-A1**2)
0049 B1=B1*DSQRT(1ONE+USQRT(ONE+TAN1**2))/TWO

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Program 4 (cont.)

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0050 TAN1=TWO*A1*B1/(B1**2-A1**2)
0051 Q1=ONE/TAN1
0052 MV=M(I)
0053 DT=MV*PI1/R1
0054 D3=DT-D1(I)-D2
0055 K2=5.D-1*C*M(I)*(ONE/FS-ONE/FE)/D2+ONE
0056 K221=DT*(ONE/QS-ONE/QE)/(TWO*D2)
0057 TAN2=K221/K2
0058 WRITE(6,104)
0059 WRITE(6,105) QE,Q1,QS,K2,TAN2
0060 Z1=(ONE/PI12)*DSQRT(2.D-9*PI12/(1.00054*8.85*1850-14))*
20LOG(DBB/DAA)
0061 Z1R=ZONE*(Z1*DSIN((PI1-TAN1)/TWO))
0062 Z1I=ZOOONE*(Z1*DSIN(TAN1/TWO))
0063 Z1C=Z1R-Z1I
0064 THRB4=(ONE/Z1)*DSQRT(PI12**2*FE/(5.808*SIGR))
0065 THRB4C=ZONE*THRB4
0066 TH1T=DTANH(A1*DT)
0067 RZ=(PI1*DT/(WL*QE)-(TH1T+THRB4)/(ONE+TH1T*THRB4))/THRB4
0068 WRITE(6,106)
0069 WRITE(6,107) RZ,EXP1,EXPE
0070 IF(RZ.GT.100.D0) GO TO 77
0071 TH1TC=ZONE*TH1T
0072 Z5C=ZONE*(THRB4*RZ)
0073 ZB1=(TH1TC+THRB4C)/(ZONE+TH1TC+THRB4C)+Z5C
0074 ZB1R=SILLY(1)
0075 ZB1I=SILLY(2)
0076 TANCAL=ZB1R*WL/(PI1*DT)
0077 TANM=ONE/QE
0078 WRITE(6,108)
0079 WRITE(6,109) TANCAL,TANM*DT,Z5C
0080 WL=C/FS
0081 TANM=ONE/QS
0082 THRB4=THRB4*(FS/FE)**EXPE
0083 THRB4C=ZONE*THRB4
0084 ZR5=ZONE*(THRB4*RZ)
0085 A1=A1*(FS/FE)**EXP1
0086 B1=PI12*DSQRT(1.00054*D0)/WL
0087 TAN1=TWO*A1*B1/(B1**2-A1**2)
0088 B1=B1*DSQRT(ONE*DSQRT(ONE+TAN1**2))/TWO)
0089 T1=DTAN(B1*D1(I))
0090 A1C=ZONE*A1
0091 B1C=ZOOONE*B1
0092 G1=A1C*B1C
0093 TANA=DTANH(A1*D1(I))
0094 TH1R=TANA*(ONE+T1**2)/(ONE+TANA**2+T1**2)
0095 TH1I=T1*(ONE-TANA**2)/(ONE+TANA**2+T1**2)
0096 TH1RC=ZONE*TH1R
0097 TH1IC=ZOOONE*TH1I
0098 TH1=TH1RC+TH1IC
0099 A2=PI12*DSQRT(K2*(-ONE*DSQRT(ONE+TAN2**2))/TWO)/WL
0100 B2=PI12*DSQRT(K2*(ONE*DSQRT(ONE+TAN2**2))/TWO)/WL
0101 A2C=ZONE*A2
0102 B2C=ZOOONE*B2
0103 G2=A2C*B2C
0104 G12=G1/G2
0105 G21=G2/G1
0106 TANA=DTANH(A2*D2)
0107 T2=DTAN(B2*D2)
0108 TH2R=TANA*(ONE+T2**2)/(ONE+TANA**2+T2**2)
0109 TH2I=T2*(ONE-TANA**2)/(ONE+TANA**2+T2**2)
0110 TH2RC=ZONE*TH2R
0111 TH2IC=ZOOONE*TH2I
0112 TH2=TH2RC+TH2IC
0113 T3=DTAN(B1*D3)

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Program 4 (cont.)

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0114      TAHA=DTANH(A1*D3)
0115      TH3R=TAHA*(ONE+T3**2)/(ONE+TAHA**2*T3**2)
0116      TH3I=T3*(ONE-TAHA**2)/(ONE+TAHA**2*T3**2)
0117      TH3RC=ZONE*TH3R
0118      TH3IC=ZONE*TH3I
0119      TH3=TH3RC+TH3IC
0120      THRB3=G21*(TH3+THRB4C)/(ZONE+TH3*THRB4C)
0121      THRB2=G12*(TH2+THRB3)/(ZONE+TH2*THRB3)
0122      Z1R=ZONE*(Z1*DSIN((PII-TAN1)/TWO))
0123      Z1I=ZONE*(Z1*DSIN(TAN1/TWO))
0124      Z1C=Z1R+Z1I
0125      ZB1=ZB5*(TH1+THRB2)/(ZONE+TH1*THRB2)
0126      ZB1R=SILLY(1)
0127      ZB1I=SILLY(2)
0128      TANCAL=ZB1R*WL/(PII*DT)
0129      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
0130      COUNT=0
0131  440  COUNT=COUNT+1
0132      IF(COUNT.GT.3) GO TO 450
0133      DO 400 K=1,14
0134      SOLD=STEP(K)
0135      DO 600 J=1,2
0136  420  WE=ONE+STEP(K)*F(J)
0137      KOUNT=0
0138  401  KOUNT=KOUNT+1
0139      IF(KOUNT.GT.90) GO TO 450
0140      IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 411
0141      GO TO 425
0142  411  STEP(K)=STEP(K)*10.D0
0143      GO TO 420
0144  425  EROLD=ERROR
0145      K2OLD=K2
0146      K2=K2*WE
0147      A2=PII2*DSQRT(K2*(-ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
0148      B2=PII2*DSQRT(K2*(ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
0149      A2C=ZONE*A2
0150      B2C=ZONE*B2
0151      G2=A2C+B2C
0152      G12=G1/G2
0153      G21=G2/G1
0154      TAHA=DTANH(A2*D2)
0155      T2=DTAN(B2*D2)
0156      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
0157      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
0158      TH2RC=ZONE*TH2R
0159      TH2IC=ZONE*TH2I
0160      TH2=TH2RC+TH2IC
0161      THRB3=G21*(TH2+THRB4C)/(ZONE+TH2*THRB4C)
0162      THRB2=G12*(TH2+THRB3)/(ZONE+TH2*THRB3)
0163      ZB1=ZB5*(TH1+THRB2)/(ZONE+TH1*THRB2)
0164      ZB1R=SILLY(1)
0165      ZB1I=SILLY(2)
0166      TANCAL=ZB1R*WL/(PII*DT)
0167      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
0168      IF(ERROR.LE.EROLD) GO TO 401
0169      ERROR=EROLD
0170      K2=K2OLD
0171      STEP(K)=SOLD
0172  600  CONTINUE
0173      DO 700 J=1,2
0174  421  WE=ONE+STEP(K)*F(J)
0175      KOUNT=0
0176  402  KOUNT=KOUNT+1
0177      IF(KOUNT.GT.90) GO TO 450
0178      IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 412

```

Program 4 (cont.)

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```

0179      GO TO 428
0180 412 STEP(K)=STEP(K)*10.00
0181      GO TO 421
0182 428 TOLD=TAN2
0183      EROL=ERROR
0184      TAN2=TAN2*WE
0185      A2=PII2*DSQRT(K2*(-ONE+DSQRT(ONE+TAN2**2)))/TWO/WL
0186      B2=PII2*DSQRT(K2*(+ONE+DSQRT(ONE+TAN2**2)))/TWO/WL
0187      A2C=ZONE*A2
0188      B2C=ZONE*B2
0189      G2=A2C+B2C
0190      G1=G1/G2
0191      G2=G2/G1
0192      TANA=DTANH(A2*D2)
0193      T2=DTAN(B2*D2)
0194      TH2R=TANA*(ONE+T2**2)/(ONE+TANA**2*T2**2)
0195      TH2I=T2*(ONE-TANA**2)/(ONE+TANA**2*T2**2)
0196      TH2RC=ZONE*TH2R
0197      TH2IC=ZONE*TH2I
0198      TH2=TH2RC+TH2IC
0199      THRB3=G21*(TH3+THRB4C)/(ZONE+TH3*THRB4C)
0200      THRB2=G12*(TH2+THRB3)/(ZONE+TH2*THRB3)
0201      ZB1=ZB5*(TH1+THRB2)/(ONE+TH1*THRB2)
0202      ZB1R=SILLY(1)
0203      ZB1I=SILLY(2)
0204      TANCAL=ZB1R*WL/(PII*DT)
0205      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
0206      IF(ERROR.LE.EROLD) GO TO 402
0207      TAN2=TOLD
0208      ERROR=EROLD
0209      STEP(K)=SOLD
0210 700 CONTINUE
0211      IF(ERROR.LE.1.D-6) GO TO 450
0212 400 CONTINUE
0213 450 TAN2=TAN2-TAN1
0214      WRITE(6,112)
0215      WRITE(6,113) TANH,TAN2,K2,ZB1R,ZB1I,TAN1,ERROR,K
0216 10 CONTINUE
0217      GO TO ??
0218 84 CALL EXIT
0219      END

```

Print-Out of the Program

EICHORN X-DPDA0166,150MHz,4/9/76 DFD4960,300MHz,3/10/76 SIGR=.3

FREQ. EMPTY MHZ	FREQ. SAMPLE-1# MHZ	DQ-CN
159.907668	159.795774	44.83100
319.670542	319.472714	19.86280

SAMPLE THICK CM	NO. HALF WAVES
3.40589	1
4.70357	2

Q-EMPTY	Q-THEO.WALL	Q-WITH SAMPLE	DIE-CONST	LOSS TANGENT
1428.6072	4482.5744	1370.9779	2.24965	0.00016000

END LOSS MULTIPLYING FACTOR	WALL LOSS EXPONENT	END LOSS EXPONENT
6.395094	0.500000	0.500000

TANCAL	TANM	CAVITY LENGTH-CN	END LOSS
0.00069998	0.00069998	93.74672	(0.669168D-03) 0.0

TANM	TAN2	DIE-CONST	Z, REAL	Z, INAG.
0.00072941	0.00002451	2.25698	0.109571D-02	-6.689185D-06

TAN1	ERROR	K
0.00022809	0.689185D-06	8

Program 5. Attenuation and Insertion Loss and Phase Shift in Multilayer
Radome for Perpendicular Incidence

```

0001  INTEGER*4 I,J,JJ,K,N,KOUNT,M
0002  REAL*8 T,TA,ALP,BET,K2,PII3,ONE,WL,FAKE(2),A,B,C,D,AB,AA,RB,AR,BR,
      ZERROR1,WE,HOLD,EROLD,AOLD,TAA,TAB,DEV,ABC,ABD,K1,TAN,COM,SOLD,
      7STEP(22)/1.5D-2,1.2D-2,1.0D-2,7.0D-3,5.0D-3,2.0D-3,1.0D-3,5.0D-4,2.0D-4,
      81.0D-4,5.0D-5,2.0D-5,1.0D-5,5.0D-6,2.0D-6,1.0D-6,1.0D-7,1.0D-8,1.0D-9,
      91.0D-10,1.0D-11,1.0D-12/,F(2)/1.,-1./,P,OB,EV2,SILLY(2),FUN(2),
      6R,RR,FR,GR,THETA,TGH2A,TG2B,B2,AAA,ZETAM,VSWR,REFI,KEFF,DA,TANEF,
      7EB1R,EB1I,EB12,INSL,FUSS(2)
0003  COMPLEX*16 ZONE,ZOONE,ALPC,BETC,GAMMA,K1C,K2C,KC,ZO,Z,THRR,RB,
      2TH,ZB,SHGRR,SHGRI,SHGR,SHGI,E,EV,YB,ZETA,EB1,EB,SHGC,SHGRC
0004  DIMENSION DATE(19),ALP(10),BET(10),GAMMA(10),Z(10),P(11),OBS(10),
      ZAR(10),BR(10),RB(10),TH(10),E(11),ZB(11),K1(10),TAN(10),T(10),
      3SHGRC(10),SHGC(10),EB(11)
0005  EQUIVALENCE (FAKE(1),THRR),(SILLY(1),EV),(FUN(1),YB),(FUSS(1),EB1)
0006  NAMELIST/IN/X1,TAN,T,N,WL/OUT/GAMMA,Z,ZB/OUT1/A,B,ERROR1,C,
      2O/OUT3/C,D/OUT2/RB,TH,ZB,SHGRR,SHGRI,SHGR,SHGI,A,B,E,THRR,THETR,
      3ERROR1,EB1,EB,SHGC,SHGRC
0007  202 FORMAT(1H0,23X,9H LAYER NO.,4X,2HK1,6X,9HTAN DELTA,1X,
      212H THICKNESS,CM,2X,20H ACCUMALATIVE LOSS,DB,2X,13H LAYER LOSS,DB,
      32X,16H PHASE SHIFT,DEG.)
0008  300 FORMAT(28X,12,2X,F9.5,2X,F11.7,2X,F8.4,10X,F11.7,6X,F11.7,9X,F8.3)
0009  302 FORMAT(25X,11H INPUT VSWR=,1X,F9.6,4X,20H REFLECTION LOSS, DB=,1X,
      2F8.5)
0010  303 FORMAT(25X,12H EFFECTIVE <=,1X,F9.6,3X,21H EFFECTIVE TAN DELTA =,
      21X,F10.7)
0011  201 FORMAT(1H0,20X,19A4)
0012  200 FORMAT(1X,19A4)
0013  305 FORMAT(1X,19H INSERTION LOSS, DB=,F11.7)
0014  77 READ(5,200,END=88) DATE
0015  WRITE(6,201) DATE
0016  READ(5,IN)
0017  PII=3.1415926536D0
0018  PII2=6.2831853072D0
0019  PII3=PII2/WL
0020  ONE=1.00
0021  ZONE=(1.00,0.00)
0022  ZOONE=(0.00,1.00)
0023  Z0=377.00*ZONE
0024  DO 10 J=1,N
0025  TA=DSORT(ONE*TAN(J)**2)
0026  ALP(J)=PII3*DSORT(K1(J)*5.0D-1*(TA-ONE))*T(J)
0027  BET(J)=PII3*DSORT(K1(J)*5.0D-1*(TA+ONE))*T(J)
0028  ALPC=ZONE*ALP(J)
0029  BETC=ZOONE*BET(J)
0030  GAMMA(J)=ALPC*BETC
0031  K2=K1(J)*TAN(J)
0032  K2C=ZOONE*K2
0033  K1C=K1(J)*ZONE
0034  KC=K1C*K2C
0035  Z(J)=Z0/CDSORT(KC)
0036  10 CONTINUE
0037  SUM=0.00
0038  E(1)=ZONE
0039  P(1)=ONE/377.00
0040  Z(N+1)=Z0
0041  ZB(1)=Z0
0042  THRR=Z0/Z(1)
0043  WRITE(6,202)
0044  DO 13 J=1,N
0045  C=FAKE(1)
0046  D=FAKE(2)
0047  R=DSORT(C**2+D**2)
0048  IF(R.GT. ONE) GO TO 33

```

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Program 5 (cont.)

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```

0049      FR=2.00*R/(ONE+R**2)
0050      GR=2.00*R/(ONE-R**2)
0051      THETA=ATAN(D/C)
0052      TGH2A=FR*DCOS(THETA)
0053      TG2B=GR*DSIN(THETA)
0054      GO TO 34
0055  33  RR=ONE/R
0056      FR=2.00*RR/(ONE+RR**2)
0057      GR=-2.00*RR/(ONE-RR**2)
0058      THETA=ATAN(D/C)
0059      TGH2A=FR*DCOS(THETA)
0060      TG2B=GR*DSIN(THETA)
0061  34  B2=ATAN(TG2B)
0062      IF(R.GT.ONE) B2=PII+R2
0063      B=DTAN(0.500*B2)
0064      AAA=0.2500*DLOG((ONE+TGH2A)/(ONE-TGH2A))
0065      A=DTANH(AAA)
0066  50  AB=ONE+(A*B)**2
0067      ARC=(A*(ONE+B**2)/AB-C)**2
0068      ABD=(B*(ONE-A**2)/AB-D)**2
0069      ERROR1=DSQRT(ARC+ABD)
0070      DO 400 K=1.22
0071      SOLD=STEP(K)
0072      DO 600 JJ=1.2
0073  420  WE=ONE+STEP(K)*F(JJ)
0074      KOUNT=0
0075  401  KOUNT=KOUNT+1
0076  425  BOLD=B
0077      EROLD=ERROR1
0078      B=B*WE
0079      AB=ONE+(A*B)**2
0080      ARC=(A*(ONE+B**2)/AB-C)**2
0081      ABD=(B*(ONE-A**2)/AB-D)**2
0082      ERROR1=DSQRT(ARC+ABD)
0083      IF(ERROR1.LE.EROLD) GO TO 401
0084      B=BOLD
0085      ERROR1=EROLD
0086      STEP(K)=SOLD
0087  600  CONTINUE
0088      DO 700 JJ=1.2
0089  421  WE=ONE+STEP(K)*F(JJ)
0090      KOUNT=0
0091  402  KOUNT=KOUNT+1
0092  428  AOLD=A
0093      EROLD=ERROR1
0094      A=A*WE
0095      AB=ONE+(A*B)**2
0096      ARC=(A*(ONE+B**2)/AB-C)**2
0097      ABD=(B*(ONE-A**2)/AB-D)**2
0098      ERROR1=DSQRT(ARC+ABD)
0099      IF(ERROR1.LE.EROLD) GO TO 402
0100      A=AOLD
0101      ERROR1=EROLD
0102      STEP(K)=SOLD
0103  700  CONTINUE
0104      IF(ERROR1.LE.1.D-12) GO TO 450
0105  400  CONTINUE
0106  450  AR(J)=0.500*DLOG((1+A)/(1-A))
0107      BR(J)=ATAN(B)
0108      RR(J)=ZONE*AR(J)+200NF*BR(J)
0109      AA=ALP(J)*AR(J)
0110      RB=RET(J)*RR(J)
0111      TAA=DTANH(AA)

```


Program 5 (cont.)

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```

0112      TAB=DTAN(BR)
0113      DEN=ONE*(TAA*TAB)**2
0114      TH(J)=ZONE*(TAA*(ONE+TAB**2)/DEN)+ZOOONE*(TAB*(ONE-TAA**2)/DEN)
0115      ZB(J+1)=Z(J)*TH(J)
0116      THRB=ZB(J+1)/Z(J+1)
0117      SHGRR=ZONE*(DSINH(AA)*DCOS(BB))
0118      SHGRI=ZOOONE*(DCOSH(AA)*DSIN(BB))
0119      SHGR=ZONE*(DSINH(AR(J))*DCOS(BR(J)))
0120      SHGI=ZOOONE*(DCOSH(AR(J))*DSIN(BR(J)))
0121      SHGC(J)=SHGR+SHGI
0122      SHGRC(J)=SHGRR+SHGRI
0123      E(J+1)=E(J)*(SHGRR+SHGRI)/(SHGR+SHGI)
0124      YB=ZONE/ZB(J+1)
0125      EV=E(J+1)
0126      EV2=SILLY(1)**2+SILLY(2)**2
0127      P(J+1)=EV2*FUN(1)
0128      THETR=DATAN(SILLY(2)/SILLY(1))
0129      IF(SILLY(2).LT. 0.00 .AND. SILLY(1).GT. 0.00) THETR=THETR+PII2
0130      IF(SILLY(2).LT. 0.00 .AND. SILLY(1).LT. 0.00) THETR=THETR+PII
0131      IF(SILLY(2).GT. 0.00 .AND. SILLY(1).LT. 0.00) THETR=THETR+PII
0132      SUM=T(J)+SUM
0133      X=2.00*SUM/WL
0134      Q=0.00
0135      IF(X.GT. 0) GO TO 12
0136      GO TO 14
0137  12 Q=Q+ONE
0138      IF(X.GT. 0) GO TO 12
0139  14 Q=Q+ONE
0140      THETO=57.295779500*THETR*0*180.00-360.00*SUM/WL
0141      IF(THETO.GT. 180.00) THETO=THETO-180.00
0142      DBS(J)=10.00*DLOG10(P(J+1)/P(J))
0143      DB=10.00*DLOG10(P(J+1)/P(1))
0144      WRITE(6,300) J,K1(J),TAN(J),T(J),DB,DBS(J),THETO
0145  13 CONTINUE
0146      ER(N+1)=ZB(N+1)/(Z0+ZB(N+1))
0147      DO 15 J=1,N
0148      M=N+1-J
0149      ER(M)=ER(M+1)*SHGC(M)/SHGRC(M)
0150  15 CONTINUE
0151      EB1=EB(1)
0152      EB1R=FUSS(1)
0153      EB1I=FUSS(2)
0154      EB12=EB1R**2+EB1I**2
0155      INSL=10.00*DLOG10(.2500/EB12)
0156      WRITE(6,305) INSL
0157      ZETA=(ZB(N+1)-Z0)/(ZB(N+1)+Z0)
0158      ZETAM=C0ABS(ZETA)
0159      VSMR=(ONE+ZETAM)/(ONE-ZETAM)
0160      REFL=10.00*DLOG10(ONE/(ONE-ZETAM**2))
0161      WRITE(6,302) VSMR,REFL
0162      KEFF=(WL*THETO/(360.00*SUM)+ONE)**2
0163      DA=38.59038900*SUM*DSORT(KEFF)/(DB*WL)
0164      TANEF=DSORT(2.00/DA**2+ONE/DA**4)
0165      WRITE(6,303) KEFF,TANEF
0166      GO TO 77
0167  88 CALL EXIT
0168      END

```

Program 5 (cont.)

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Print-Out of the Program

ROCKWELL 9-LAYER RADOME 3 GHZ 74 DEG.P.

LAYER NO.	K1	TAN DELTA	THICKNESS, CM	ACCUMULATIVE LOSS, DB
1	2.44000	0.0068000	0.0530	0.0009846
2	1.11550	0.0000900	5.0800	0.0023020
3	3.59000	0.0125000	0.0500	0.0040788
4	1.21500	0.0033900	0.2640	0.0067270
5	3.59000	0.0125000	0.0500	0.0086609
6	4.14000	0.0100000	0.0660	0.0108214
7	1.12500	0.0027000	1.2280	0.0236838
8	4.14000	0.0100000	0.0660	0.0262639
9	1.30400	0.0045300	0.3200	0.0317474

LAYER LOSS, DB	PHASE SHIFT, DEG.
0.0009846	0.001
0.0013174	9.743
0.0017768	9.800
0.0026482	10.382
0.0019339	10.558
0.0021605	10.840
0.0128623	27.576
0.0025801	28.559
0.0054834	32.756

INSERTION LOSS. DB= 0.1499004

INPUT VSWR= 1.391807 REFLECTION LOSS, DB= 0.11415
EFFECTIVE K= 1.267634 EFFECTIVE TAN DELTA = 0.0014387

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DIELECTRIC PARAMETERS

Dielectric parameters in the present report have the following notation:

κ' , ϵ'/ϵ_0 , dielectric constant relative to vacuum

κ'' , ϵ''/ϵ_0 , dielectric loss factor relative to vacuum

$\tan \delta$, or $\tan \delta_d$, dielectric loss tangent (dissipation factor)

κ'_m , μ'/μ_0 , magnetic permeability relative to vacuum

κ''_m , μ''/μ_0 , magnetic loss factor

$\tan \delta_m$, magnetic loss tangent

σ , a.c. volume conductivity in mho-cm

ρ , a.c. volume resistivity in ohm-cm

MATERIALS INDEX

I. INORGANIC COMPOUNDS

Aluminum oxides

Single crystal, sapphire

Union Carbide

Sample Code M7-2054-7, 8.515 GHz, 25°C

Field direction relative
to optic axis

κ'

$\tan \delta$

||

$11.60 \pm .03$

$.00005 \pm .00003$

⊥

$9.40 \pm .02$

$.00007 \pm .00005$

Ceramic, AlSiMag 772

American Lava

8.515 GHz, 25°C

D-c volume resistivity at 25°C $> 2 \times 10^{15}$ ohm-cm

$\kappa = 9.295 \pm .03$, $\tan \delta = .000073 \pm .000015$

Ceramic, high alumina

A.C. Spark Plug

T°C	ρ (ohm-cm)	T°C	ρ (ohm-cm)
25	$> 1.E17$	500	$2.25E8$
60	$1.E16$	600	$6.3E7$
100	$2.E15$	700	$1.53E7$
200	$1.9E12$	800	$3.22E6$
300	$4.0E10$	900	$6.1E5$
400	$2.32E9$		

Breakdown voltage 60 Hz rms, .007" thick-
ness, 1/8" diam. elect., short-time test

T°C	kV
23	8.0
137	7.0
237	6.0

Aluminum oxide mixtures
With boron nitride

Ceradyne

% Comp. Al ₂ O ₃	w/o BN	Ceradyne No.	Density (g/cm ³)	25°C κ'	8.5 GHz $\tan \delta$
60	40	1603	2.87	6.61	.0004
70	30	1605	2.98	6.92	.00036
50	50	1597	2.603	6.01	.0026
50	50	1595	2.832	6.52	.00045

Aluminum oxide mixtures (cont.)

With silicate fibers

McDonnell Douglas

After drying for 48 hrs at 150°C

Density 1.65 g/cm³

8.5 GHz, 25°C

$\kappa = 2.88$ $\tan \delta = .00235$

Ammonia

Matheson

Solid

8.5 GHz			14 GHz		
T°C	κ'	$\tan \delta$	κ'	$\tan \delta$	
-195	2.96	.00034	2.96	.00032	
-160	2.96	.00035	2.96	.00034	
-140	2.97	.00036	2.97	.00035	
-130	2.98	.00037	2.98	.00037	
-120	3.00	.00039	3.00	.00038	
-110	3.02	.00044	3.02	.0005	
-105	3.03	.00050	3.03	.0007	
-100	3.04	.0020	3.03	.00132	
-95	3.04	.0054	3.04	.0026	
-90	3.05	.0049	3.04	.0053	
-85	3.07	.0046	3.06	.0035	
-80	3.14	.0047	3.12	.0025	

Liquid

8.515 GHz			14.0 GHz		
T°C	κ'	κ''	T°C	κ'	κ''
-76.2	24.52	6.85	-76.5	19.24	9.57
72.6	24.44	6.81	75.	19.33	9.48
71.7	24.38	6.44	72.4	19.50	9.37
67.0	24.14	6.08	68	19.69	8.72
64.5	24.00	5.65	61.7	19.99	7.80
62.0	23.87	5.30	59.5	20.14	7.54
57.7	23.58	4.91	56.3	20.5	7.12
51.2	23.08	4.28	52.4	20.76	6.65
47.7	22.77	4.01	48.7	20.86	6.24
42.0	22.23	3.61	44.2	21.42	5.78
40.3	22.04	3.51	41.5	21.07	5.56
38.3	21.82	3.40	38.7	21.08	5.33
34.5	21.46	3.21	36.3	21.08	5.07
33.9	21.35	3.19	33.6	21.07	4.96

Beryllium oxide + silicon nitride ceramic

"Fiberlox"

National Beryllia

8.5 GHz, 25°C

$\kappa' = 7.242$ $\tan \delta = .00235$

Beryllium oxide + silicon nitride ceramic (cont.)

"Niberlox"

National Beryllia

3.13 to 2.94 GHz

5.1 to 4.89 GHz

T°C	κ'	$\tan \delta$	T°C	κ'	$\tan \delta$
25	7.245	.00117	25	7.21	.001
98	7.304	.00118	500	7.73	.0015
191	7.396	.00119	600	7.85	.0022
254	7.458	.00110	700	7.99	.0029
362	7.578	.00113	800	8.15	.0032
438	7.665	.00124	900	8.30	.0042
471	7.703	.00142	1000	8.47	.0049
515	7.765	.00165	1100	8.65	.0057
554	7.823	.00200	1200	8.80	.0071
592	7.872	.00245	1220	8.84	.0075
643	7.955	.00301	1250	8.88	.0083
675	8.002	.00329	1277	8.91	.0092
696	8.033	.00344	1305	8.96	.0118
735	8.106	.00375	1327	9.01	.0210
768	8.171	.0039	1335	9.02	.0035
			1343	9.05	.0037

Boron nitride, hot-pressed, grade HBC

Union Carbide

Electric field || pressing direction

T°C	Freq., Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^8
23	κ	4.63	4.63	4.63	4.63	4.63	4.63	4.63
	$\tan \delta$	3.6	3.2	2.7	2.5	.79	<.6	<.6
100	κ	4.68	4.65	4.64	4.64	4.64	4.64	-
	$\tan \delta$	12.7	12.9	11.1	8.2	3.7	2.	-
200	κ	4.70	4.68	4.68	4.67	4.64	4.64	-
	$\tan \delta$	29.6	25.8	20.7	14.6	6.1	2.	-
300	κ	4.90	4.81	4.75	4.71	4.71	4.72	-
	$\tan \delta$	136.	108.	66.	25.7	8.7	3.8	-
400	κ	4.99	4.88	4.81	4.76	4.74	4.72	-
	$\tan \delta$	163.5	142.5	97.	43.3	13.6	4.3	-
500	κ	5.07	5.92	4.85	4.80	4.76	4.74	-
	$\tan \delta$	266.	172.	116.	87.5	48.3	16.5	-

All values of $\tan \delta$ are multiplied by 10^4 .

Boron nitride, hot-pressed, grade HBC

Electric field \perp pressing direction

4.08 to 3.99 GHz			8.515 GHz		
T°C	κ'	$10^4 \times \tan \delta$	T°C	κ'	$10^4 \times \tan \delta$
25	4.142	1.4	25	4.142	1.5
100	4.146	1.5	100	4.14	1.6
200	4.154	2.5	200	4.15	1.6
300	4.162	3.4	300	4.16	1.7
400	4.172	3.8	400	4.17	1.8
Overnight hot			500	4.18	1.8
500	4.181	2.7	600	4.19	1.8
600	4.193	2.4	700	4.20	1.8
700	4.205	2.7	800	4.22	2.0
800	4.221	3.2	Anisotropy test on rod at 8.515 GHz, 25°C		
900	4.237	4.			
1000	4.254	5.1	Field direction	κ'	$10^4 \times \tan \delta$
1100	4.271	6.5	E \perp	4.150	9.4
1200	4.290	16.2	E \parallel	4.543	5.6
1300	4.308	24.			
1350	4.317	33.3			
1375	4.321	38.			
1400	4.326	42.			
1425	4.331	48.			
1500	4.345	68.			

Potassium bromide, hot-pressed

Union Carbide

25°C, 8.515 GHz after 48 hrs. at 150°C

Sample No.	Density (g/cm ³)	κ'	$\tan \delta$
15	2.10	3.573	.00006
16	2.14	3.496	.00013
17	2.43	4.320	.00094
18	2.48	4.118	.00006

Silica, Dynasil 4000

Dynasil Corp.

8.5 to 8.6 GHz

37.3 to 35.1 GHz

T°C	κ'	$\tan \delta$	T°C	κ'	$\tan \delta$
25	3.825	.00016	23	3.82 \pm .015	.00035 \pm .0001
92	3.830	.00012	195	3.84	.0003
189	3.836	.00010	403	3.86	.0003
272	3.840	.00007	610	3.87	.0002
337	3.844	.00006	807	3.89	.0002
398	3.850	.00006	1003	3.92	.0003
544	3.864	.00007	1205	3.95	.0003
601	3.868	.00008	1408	4.01	.0004
700	3.880	.00012	1495	4.05	.0005
833	3.897	.00015	1570	4.08	.0007
862	3.904	.00016	1650	4.14	.0010
922	3.914	.00018	1690	4.18	.0018
997	3.925	.00020	1720	4.22	.0025
1064	3.936	.00024	1750	4.26 \pm .04	.0038 \pm .0004
1099	3.941	.00025	1800	4.41*	.010*
1111	3.942	.00025			
1181	3.956	.00027			
1234	3.966	.00029			
1316	3.984	.00031			
1364	3.991	.00034			

* Extrapolated, not measured.

Silica, hot-pressed

McDonnell Douglas

8.5 GHz, 25°C

Sample	Density (g/cm ³)	κ'	$\tan \delta$
Standard Hyperpure			
SC 195	1.55	2.703	.00033
SC 103	2.07	3.604	.00004
Aggregate Hyperpure			
ASC-71	1.55	2.747	<.00002
ASC-83	1.96	3.268	.00016

Silica fiber AS-3DX 176-17

Philco-Ford

8.5 to 8.6 GHz

T°C	κ'	$\tan \delta$	T°C	κ'	$\tan \delta$
25	2.88	.00178	959	2.94	.0026
70	2.88	.00150	1001	2.94	.0030
126	2.88	.00103	1050	2.94	.0034
202	2.876	.00060	1080	2.95	.0038
300	2.88	.00035	1173	2.95	.0047
335	2.89	.00035	1223	2.97	.0053
488	2.89	.00048	1252	2.97	.0058
609	2.90	.00077	1289	2.98	.0068
680	2.91	.0010	1324	3.02	.011
799	2.93	.00155			

Silicate Glasses

Corning Glass 7052

Corning Glass 7056

1 GHz			1 GHz		
T°C	κ'	$\tan \delta$	T°C	κ'	$\tan \delta$
23	4.97	.0046	23	5.23	.0049
102	5.00	.0053	106	5.26	.0050
198	5.04	.0068	228	5.20	.0066
305	5.12	.0106	295	5.31	.0078
359	5.18	.0150	352	5.34	.0102
393	5.23	.0165	404	5.40	.0123
445	5.31	.0174	447	5.43	.0154
490	5.35	.0254	494	5.49	.0173
511	-	.0306	514	-	.0360
529	-	.0438	529	-	.0441
540	-	.0498	545	-	.0538
552	-	.0582	562	-	.0653
560	-	.0657	577	-	.0731
573	-	.0750	593	-	.0806
594	-	.0874	612	-	.0893
603	-	.0930	636	-	.102
622	-	.0977			
632	-	.1017			

Silicon nitride compounds

General Electric

		8.515 GHz	14 GHz	24 GHz
GE 128-2	κ'	7.72	7.71	7.67
	$\tan \delta$.0022	.0033	.0034
	ρ (g/cm ³)	3.082	3.080	3.079
GE 129-1	κ	7.77	7.73	7.67
	$\tan \delta$.00185	.0026	.0020
	ρ (g/cm ³)	3.087	3.089	3.080

II. MISCELLANEOUS INORGANICS

Hercynite (FeAl₂O₄) in air

M.I.T. Materials Science

T°C	Freq., Hz	κ'	σ	T°C	Freq., Hz	σ
28	1.E5	18+2	5.8E-8	527	100	1.1E-4
61	↓		7.2E-8	686	100	8.2E-4
101			9.8E-8	686	1.E5	8.2E-4
170			2.0E-7	718	↓	1.07E-3
221			4.2E-7	778		2.09E-3
260			8.3E-7	829		2.96E-3
299	↓		1.7E-6	836	1.E6	3.79E-3
324			2.9E-6	885	↓	8.8E-3
421			2.1E-5	905		1.14E-2
537			1.2E-4	971		1.68E-2

Sand

M.I.T., Research Laboratory for Electronics

	Freq., GHz	.3	1	3	8.5	14	24
.2% H ₂ O	κ'	2.95	2.93	2.91	2.90	2.89	2.86
	κ''	.0196	.017	.018	.0091	.0096	.0158
3% H ₂ O	κ'	3.68	3.98	3.52	.50	3.48	3.46
	κ''	.273	.122	.136	.36	.47	.48
5% H ₂ O	κ'	5.07	4.90	3.53	4.65	4.50	4.24
	κ''	.355	.220	.352	.630	.89	.935
8% H ₂ O	κ'	6.57	6.46	6.27	6.06	5.54	5.30
	κ''	.493	.309	.462	1.18	1.53	3.1
11% H ₂ O	κ'	8.6	8.45	8.24	8.18	7.8	6.99
	κ''	.785	.43	.691	1.69	2.42	2.60
20% H ₂ O	κ'	15.2	15.1	14.8	13.8	12.4	11.0
	κ''	1.15	.66	1.55	3.94	5.90	5.4

Uranium oxide (UO₃) powder

General Electric

.915 GHz			2.45 GHz		
T°C	κ'	tan δ	T°C	κ'	tan δ
23	4.27	.00067	23	4.27	.00058
93	4.26	.00092	98	4.27	.00115
272	4.26	.00550	264	4.26	.00292
345	4.28	.00783	359	4.27	.0053
482	4.32	.0106	456	4.28	.0071
517	4.35	.0125	517	4.32	.0101

Chalcopyrite (CuFeS₂) powders

Kennecott Copper

Sample	Freq.	1 GHz	3 GHz	8.5 GHz
Course	κ'	10.38	9.07	7.37
Messina	κ''	2.32	2.09	2.49
-16 + 20 mesh	tan δ	.223	.221	.338
	σ	1.29E-3	3.48E-3	1.18E-2
	α	.64	1.88	6.83
Fine	κ'	10.07	6.61	5.83
UCD	κ''	.745	.32	.186
-120 mesh	tan δ	.074	.0484	.0319
	σ	4.14E-4	5.33E-4	8.8E-4
	α	.213	.339	.596

The conductivity (σ) is expressed in reciprocal ohm-cm. The absorption coefficient (α) is in db/cm.

Supramica 1100

Mycalox

T°C	Freq., Hz	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁸	10 ⁹	8.319	1.4210	2.4710
23	κ'	6.95	4.97	6.89	6.85	6.82	6.80	6.77	7.52	7.49	7.46	7.42
	tan δ	.00488	.00465	.00318	.00312	.00175	.00133	.0021	.0031	.00413	.0048	.0056
100	κ'	7.22	7.04	6.97	6.94	6.90	6.82		7.54	7.49	7.46	7.44
	tan δ	.0100	.0119	.0063	.0031	.0039	.0027		.0037	.00470	.0054	.0040
200	κ'	6.51	7.33	7.47	7.16	6.87	6.66		7.59	7.51	7.52	7.47
	tan δ	.134	.183	.0133	.0117	.00824	.00643		.0031	.00498	.0064	.0071
300	κ'	26.0	14.04	9.84	7.74	7.30	7.05		7.64	7.60	7.58	7.53
	tan δ	.972	.483	.221	.092	.0363	.0159		.0092	.00681	.0080	.0078
450	κ'					9.20	7.49		7.82	7.89	7.67	7.62
	tan δ					.1536	.0129		.0193	.0106	.0122	.0131
450	κ'								7.93	7.80	7.78	7.71
	tan δ								.014	.0146	.0153	.0166
500	κ'					13.89	9.41		8.05	7.93	7.91	7.84
	tan δ					.472	.242		.0215	.0201	.0213	.0233
540	κ'					18.4	13.3		4.17	8.15	8.08	7.98
	tan δ					.67	.343		.040	.0115	.0338	.034

In frequency range 10² to 10⁸ electric field is perpendicular to sheet stock; at higher frequencies the field is parallel.

III. ORGANICS

Epoxy compound

Allied Resin

T°C	Freq., Hz	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶
25	κ'	4.12	4.046	4.009	3.933	3.856
	$\tan \delta$.0177	.0111	.0105	.01295	.0152
100	κ	4.85	4.518	4.354	4.244	4.125
	$\tan \delta$.0779	.0448	.0258	.0202	.0189

Black FM Film

American Cyanamid

T°C	Freq., GHz	1	3	8.5
25	κ'	7.24	6.45	6.06
	$\tan \delta$.202	.155	.115

"Teflon"-coated membrane

American Durafilm

25°C, 3 GHz

$$\kappa' = 3.54 \quad \tan \delta = .0071$$

"Torlon" 2000

Amoco

24 GHz, 25°C

	κ'	$\tan \delta$
40% Rel. Hum.	3.605	.0143
Wet	3.97	.0327

"Torlon" 4000

Amoco

24 GHz, 25°C

	κ'	$\tan \delta$
40% Rel. Hum.	3.524	.014
Wet	3.77	.0282

"Torlon" 4000/Astroquartz

Amoco (Whittaker)

24 GHz

T°C	κ'	$\tan \delta$	T°C	κ'	$\tan \delta$
23	3.70	.0061	220	3.73	.0097
66	3.72	.0065	260	3.52	.0142
119	3.73	.0072	119	3.47	.0076
177	3.74	.0082			

"Torlon" 4103

Amoco

8.5 GHz, 25°C

$\kappa' = 3.605$ $\tan \delta = .0120$

"Torlon" 4203

Amoco

8.5 GHz, 25°C

$\kappa' = 3.776$ $\tan \delta = .0117$

Fluorglass laminate

Atlantic Laminates

1.3 GHz, 25°C

$\kappa' = 2.515$ $\tan \delta = .00138$

Absorber

AVCO

1 GHz

T°C	ϵ'/ϵ_0	$\tan \delta_d$	μ'/μ_0	$\tan \delta_m$	Attenuation (db/cm)
-30	6.99	.093	2.38	.949	3.61
-20	7.06	.101	2.37	.979	3.75
-10	7.14	.116	2.36	1.01	3.91
0	7.23	.129	2.36	1.04	4.08
10	7.34	.144	2.35	1.09	4.31
20	7.46	.160	2.35	1.15	4.58
25	7.53	.169	2.34	1.165	4.69
30	7.60	.179	2.31	1.184	4.78
40	7.74	.198	2.19	1.22	4.89
50	7.83	.217	2.11	1.25	4.99

Vinyl film 133-24413-L

Borden

18 MHz

T°C	κ'	$\tan \delta$	T°C	κ'	$\tan \delta$
32.5	2.915	.0496	115.7	4.969	.251
37.5	2.963	.0568	125	5.364	.238
46.9	3.064	.0733	129	5.599	.228
54.5	3.063	.0968	134.2	5.799	.228
66.4	3.328	.130	140.4	5.046	.191
75.7	3.620	.1566	152.2	6.317	.148
81.5	3.748	.182	156	6.423	.133
91.5	3.988	.214	159.5	6.497	.121
99.9	4.302	.237	163.5	6.546	.110
108	4.618	.248			

Adhesive, HA5164 XLS-101

Borden

100 MHz

T°C	κ'	$\tan \delta$	T°F	κ'	$\tan \delta$
79	2.61	.0195	188	2.69	.0666
89	2.42	.0223	218	2.80	.0671
113	2.47	.0327	255	2.86	.0607
150	2.54	.0511	275	2.90	.0481

"Astral" 360 polyaryl

Carborundum

8.5 GHz, 25°C

$$\kappa' = 3.454 \quad \tan \delta = .01215$$

"Ekkcel" I 200 copolyester

Carborundum

8.5 GHz, 25°C

	κ'	$\tan \delta$
Piece 1	3.158-3.183	.00358-.00362
Piece 2	3.268-3.297	.00367-.00289

Polyimide film

Carborundum

T°C	Freq.	d.c.	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
25*	κ'		3.50	3.49	3.48	3.44	3.27
	$\tan \delta$.00203	.00276	.00541	.00883	.00854
	ρ	>1.E18					
100	κ'		2.99	2.99	2.98	2.973	2.93
	$\tan \delta$.00220	.00179	.00221	.00190	.0011
	ρ	6+3E16					
25	κ'		2.99	2.99	2.98	2.98	2.94
	$\tan \delta$.00202	.00109	.00125	.00144	.00109
	ρ	>1.E18	2.98E12				
-75	κ'		2.98	2.98	2.98	2.97	2.94
	$\tan \delta$.00012	.00096	.00126	.00129	.00203
	ρ	>1.E18					
200	κ'		2.89	2.86	2.84	2.82	2.78
	$\tan \delta$.0147	.00729	.00382	.00210	.00135
	ρ	4.3E11	4.21E11				
235†	ρ	5.E9					
257†	ρ	5.E8					
260	ρ	2.2E8					
256	κ'		38.8	6.46	2.89	2.64	2.56
	$\tan \delta$		8.24	5.74	2.05	.141	.0145
	ρ		5.63E8	4.85E8			
282†	κ'			10.85			
	$\tan \delta$			8.30			
	ρ			2.0E7			
300	κ'		5.22	9.93	3.36	2.62	2.50
	$\tan \delta$		30.15	15.4	5.49	.777	.0925
	ρ	1.03E7	1.14E7	1.18E7			

* As received condition; for all other data sample was in dry N₂ after heating to 150°C.

† Not in thermal equilibrium.

Epoxy/Glass laminate Fortin "No Flow"

"B" stage pressed into "C" stage

Collins Radio

E \perp to sheet					E \parallel to sheet				
1 MHz			10 MHz		1 GHz			3 GHz	
T ^o C	κ'	tan δ	κ'	tan δ	T ^o C	κ'	tan δ	κ'	tan δ
-55	3.94	.0156	3.73	.0139	-55	3.73	.0058	3.71	.0105
-40	4.00	.0182	3.76	.0162	-40	3.74	.0097	3.72	.0126
-20	4.11	.0223	3.87	.0212	-20	3.75	.0153	3.73	.0156
0	4.23	.0259	3.97	.0271	0	3.77	.0212	3.74	.0206
10	4.30	.0267	4.03	.0300	25	3.82	.0295	3.78	.0278
23.8	4.43	.0280	4.14	.0336	40	3.87	.0346	3.83	.0323
40	4.60	.0258	4.29	.0370	60	3.94	.041	3.88	.0390
60	4.84	.0239	4.51	.0349	80	4.06	.049	3.97	.047
80	5.07	.0227	4.72	.0330	100	4.19	.058	4.08	.0552
100	5.28	.0275	4.87	.0345	120	4.32	.064	4.21	.0636
115	5.42	.0380	5.01	.0387	125	4.39	.067	4.25	.0658
125	5.57	.0452	5.08	.0426					

100 MHz

25 4.02 .0339

E \parallel to sheet, 8.5 GHz

T ^o C	κ'	tan δ	T ^o C	κ'	tan δ
-55.5	3.699	.0155	106.0	4.044	.0617
-44.	3.697	.0173	117	4.089	.0650
-32.1	3.699	.0221	125	4.142	.0673
-21	3.697	.0255	1304	4.184	.0686
- 5.4	3.723	.0294	77	3.912	.0508
14.5	3.723	.0294	62	3.855	.0443
31.5	3.757	.0323	232	3.745	.0304
95.1	4.010	.0501			

Epoxy/Glass laminate Mica "No Flow" 102-68

Pre-preg. pressed into "C" stage

Collins Radio

E \perp to sheet					E \parallel to sheet				
1 MHz			10 MHz		1 MHz			10 MHz	
T ^o C	κ'	tan δ	κ'	tan δ	T ^o C	κ'	tan δ	κ'	tan δ
-55	3.96	.0187	3.93	.0160	50	4.71	.0253	4.48	.0366
-40	4.03	.0225	4.00	.0211	60	4.80	.0242	4.57	.0364
-30	4.10	.0251	4.04	.0225	70	4.89	.0239	4.65	.0360
-20	4.15	.0271	4.08	.0261	80	4.98	.0253	4.73	.0370
-10	4.22	.0284	4.10	.0297	90	5.06	.0277	4.84	.0385
0	4.29	.0292	4.14	.0301	100	5.17	.0309	4.96	.0403
10	4.36	.0202	4.18	.0322	110	5.29	.0371	5.08	.0423
20	4.43	.0288	4.22	.0339	115	-	-	5.15	.0435
25	4.49	.0285	4.26	.0345	120	5.41	.0461	5.08	.0469
30	4.53	.0280	4.31	.0350	125	5.48	.0509	5.00	.0510
40	4.62	.0266	4.38	.0359					

Epoxy/Glass laminate Mica "No Flow" 102-68

Pre-preg. pressed into "C" stage

Collins Radio

E // to sheet

1 GHz			3 GHz			8.5 GHz		
T°C	κ'	$\tan \delta$	κ'	$\tan \delta$		T°C	κ'	$\tan \delta$
-55	3.65	.0093	3.63	.0094		-55	3.639	.0117
-40	3.69	.0125	3.65	.0115		-40	3.653	.0130
-30	3.72	.0149	3.67	.0132		-30	3.665	.0142
-20	3.75	.0174	3.69	.0153		-20	3.684	.0161
-10	3.77	.0198	3.71	.0175		-10	3.704	.0182
0	3.79	.0222	3.73	.0200		0	3.721	.0202
10	3.81	.0244	3.75	.0228		10	3.740	.0225
25	3.86	.0279	3.785	.0269		20	3.756	.0249
40	3.89	.0316	3.82	.0313		25	3.765	.0262
50	3.93	.0342	3.855	.0340		30	3.773	.0276
60	3.99	.0373	3.89	.0384		40	3.782	.0292
70	4.05	.0413	3.93	.0425		50	3.796	.0325
80	4.14	.0454	3.985	.0468		60	3.839	.0378
90	4.23	.0467	4.05	.0515		70	3.894	.0449
100	4.33	.0538	4.10	.0560		80	3.959	.0530
110	4.42	.0574	4.15	.0605		90	4.032	.0594
120	4.52	.0604	4.21	.0648		100	4.072	.0649
125	4.55	.0624	4.23	.0665		110	4.079	.0667
						115	-	-
						120	4.076	.0691
						125	4.082	.0710

Custom Poly-"Teflon" fiberglass

Custom Materials

1.3 GHz, 25°C

$\kappa = 2.544$ $\tan \delta = .00125$

Thymol

Eastman

Solid, 45°C				Solid, 25°C		
Freq., Hz	κ'	κ''	σ	Freq., Hz	κ'	κ''
3	16.44	31.6	5.85E-11	1.5x10 ⁸	2.45-2.52	.0070
10	5.09	12.8	7.11E-11	3x10 ⁸		.0110
31	4.14	5.12	3.79E-11	5x10 ⁸		.0098
98	3.45	2.14	1.17E-10	1x10 ⁹		.0070
996	2.72	.401	2.22E-10	1.5x10 ⁹		.0055
9987	2.61	.0570	3.16E-10	2.45x10 ⁹		.0054
1x10 ⁵	2.62	.00575	3.19E-10	3x10 ⁹		.0062
1x10 ⁶	2.61	.00104	5.80E-10	4.9x10 ⁹		.0104
9.5x10 ⁶	2.61	.00134	7.07E-9	8.5x10 ⁹	2.45	.00546
1.8x10 ⁷	2.61	.00234	2.34E-8	1.4x10 ¹⁰	2.45	.0146
				2.4x10 ¹⁰	2.45	.030

Thymol (cont.)

Liquid, 52°C

Eastman

Freq., Hz	$\kappa'_{\text{meas.}}$	$\kappa'_{\text{fit}} *$	$\kappa''_{\text{meas.}}$	$\kappa''_{\text{fit}} *$
10^2	4.61	4.52	4.94	4.94
10^3	4.52	↓	.494	.494
10^4	4.50		.0494	.0494
10^5	4.50		.00512	.00502
10^6	4.50		.00157	.00127
9.5×10^6	4.50		.0105	.0074
1.8×10^7	4.50	↓	.0200	.0139
1.5×10^8	4.49	4.51	.136	.115
3×10^8	4.48	4.49	.257	.228
5×10^8	4.46	4.44	.369	.369
1×10^9	4.20	4.24	.650	.652
1.5×10^9	3.95	3.99	.727	.819
2.45×10^9	3.73	3.58	.911	.898
3×10^9	3.49	3.40	.804	.872
5×10^9	3.25	3.04	.675	.689
8.5×10^9	2.96	2.84	.510	.458
1.4×10^{10}	2.83	2.77	.392	.291
2.4×10^{10}	2.72	2.74	.359	.173

* Computer best fit results to parameters of a single relaxator plus conductance: $\kappa_{\infty} = 2.721$, $\sigma = 2.75 \times 10^{-10}$, $\kappa_g - \kappa_{\infty} = 1.799$; critical frequency 2.33×10^9 , $\tau = 6.83 \times 10^{-9}$ sec.

Silicone rubber absorbers

Emerson & Cuming

Sample	Freq., Hz	10^5	10^6	10^7	3×10^7	10^8	1.5×10^8	3×10^8	1×10^9	3×10^9
PCM 125	ϵ'/ϵ_0	8.78	7.95	7.60	7.52	7.39	7.32	7.32	7.25	7.29
	$\tan \delta_d$.190	.092	.021	.019	.016	.015	.013	.011	.097
	μ'/μ_0			12.0	11.8	9.2	8.4	7.00	3.32	1.22
	$\tan \delta_m$.04	.04	.27	.332	.500	1.04	1.74
CDS	ϵ'/ϵ_0	12.4							12.55	12.5
	$\tan \delta_d$.0046	.0041	.0044	.0044	.0046	.0047	.0049	.0041	.0113
	μ'/μ_0			3.2	4.0	3.7	3.70	3.79	1.53	2.82
	$\tan \delta_m$			<.1	<.1	.025	.036	.0614	.192	.415
PCM 40	ϵ'/ϵ_0	31.8	31.7	31.6				31.5	31.5	31.2
	$\tan \delta_d$.027	.018	.013	.012	.0088	.0062	.0048	.0033	.0109
	μ'/μ_0			7.8	7.8	7.8	7.8	7.7	7.44	5.41
	$\tan \delta_m$			<.06	<.07	.04	.059	.110	.405	.785
FDS	ϵ'/ϵ_0	7.40	6.83	6.60	6.50	6.41	6.37	6.35	6.20	6.13
	$\tan \delta_d$.065	.0323	.0117	.0103	.010	.010	.0104	.0114	.0145
	μ'/μ_0			6.5	6.5	5.4	5.16	4.64	2.76	1.325
	$\tan \delta_m$			<.05	<.05	.18	.216	.236	.713	1.686

* Interpolated values, not measured.

Carbon foam absorber

Emerson & Cuming

EHD-18-F, 25°C

Freq., GHz	κ'	κ''
1	3.16	2.43
3	2.55	1.17
8.5	1.90	.68
14	1.75	.34

Laminates

Glastic Corp.

1 GHz, 25°C

	κ'	$\tan \delta$
Glastic G-200, buff (nearly NEMA G-10)	5.07	.0192
Glastic TSF, brown (NEMA GPO-2)	4.97	.0142
Glastic UTR, red (NEMA GPO-1)	4.38	.0145

Molded polyvinyl chloride

Grace

Grace 252

30 MHz, density 1.41 g/cm³

T°C	κ'	κ''	$\tan \delta$	σ	T°C	κ'	κ''	$\tan \delta$	σ
21.0	3.032	.0288	.0095	4.81E-7	116.7	3.331	.333	.100	5.56E-6
29.5	3.054	.0299	.0098	5.0E-7	129.5	3.429	.462	.135	7.71E-6
39.3	3.055	.0470	.0154	7.85E-7	138.7	3.601	.751	.209	1.25E-5
66.0	3.076	.0504	.0164	8.41E-7	146.9	3.870	.986	.254	1.646E-5
73.7	3.106	.0666	.0214	1.11E-6	160.9	4.297	1.39	.323	2.32E-5
89.9	3.127	.0980	.0313	1.64E-6	175.5	4.673	1.615	.346	2.70E-5
104.7	3.252	.1816	.0558	3.03E-6	180.5	4.906	1.667	.340	2.78E-5

Molded co-polymer of polyvinyl chloride

Grace

Grace EM 134, 30 MHz, density 1.35 g/cm³

T°C	κ'	κ''	$\tan \delta$	σ	T°C	κ'	κ''	$\tan \delta$	σ
21.1	2.891	.054	.018	8.91E-7	121.0	3.229	.398	.123	6.64E-6
32.5	2.899	.035	.012	5.8E-7	129.3	3.326	.505	.152	8.42E-6
41.5	2.908	.0387	.013	6.5E-7	138.3	3.55	.674	.190	1.12E-5
59.9	2.932	.0553	.0189	9.2E-7	142.9	3.66	.825	.226	1.38E-5
64.9	2.940	.058	.0198	9.7E-7	147.6	3.832	.945	.247	1.58E-5
71.3	2.973	.0694	.0234	1.16E-6	163.7	4.48	1.49	.332	2.49E-5
82.9	3.007	.0903	.0300	1.51E-6	166.3	4.62	1.52	.328	2.53E-5
95.5	3.040	.129	.0426	2.17E-6	170.0	4.78	1.62	.338	2.71E-5
111.1	3.134	.272	.0866	4.53E-6	175.0	5.06	1.73	.341	2.89E-5

Diocetaphalate, Mactol 101

Hatco

Liquid, 25°C

	1 GHz	3 GHz	8.5 GHz
κ'	2.74	2.645	2.59
$\tan \delta$.109	.0635	.0438

Niax polyol, 10 ring 130, liquid

MIT, Mech. Eng. Dept.

T [°] F	Freq., kHz	κ'	σ
76.4	1	8.80	9.08E-9
87.4	1	-	1.255E-8
93.7	1	-	1.47E-8
105.2	1	-	1.90E-8
108.5	10	7.94	2.31E-8
125.2	10	-	3.03E-8
134.8	10	-	3.29E-8
141.5	10	7.81	3.40E-8
149.7	10	-	3.50E-8
159.7	10	-	3.49E-8

Niax polyol W137D408, liquid, clear

MIT, Mech. Eng. Dept.

				Same, with carbon			
T [°] C	Freq., kHz	κ'	σ		Freq., Hz	κ'	σ
74	1	9.85	3.45E-8	75	1	10.8	3.82E-8
74	10	8.37	3.76E-8	90.5	1	-	6.18E-8
74	100	7.96	5.09E-8	96	1	-	7.08E-8
88.5	1	-	4.65E-8	101	1	-	7.84E-8
106.5	1	-	6.32E-8	105	10	9.12	8.55E-8
127.2	1	-	7.89E-8	114.8	10	-	1.04E-7
141.2	1	-	8.74E-8	123	10	-	1.20E-7
152.9	10	-	9.43E-8	130.4	10	-	1.32E-7
167.1	10	-	9.55E-8	140.5	10	-	1.48E-7
171.4	10	-	9.61E-8	147.5	10	-	1.57E-7
				154	10	-	1.65E-7
				167	10	-	1.80E-7
				170.9	10	-	1.86E-7

Isocyanate, SF-52, liquid

MIT, Mech. Eng. Dept.

T [°] F	κ'	σ
83.7	14.7	2.49E-9
96	-	6.28E-9
105	-	8.50E-9
109	-	9.60E-9
122	-	1.25E-8
126	-	1.40E-8
132.7	-	1.58E-8
135	-	1.64E-8
142.7	-	1.86E-8
148.5	-	2.16E-8
153.2	-	2.39E-8
159.2	-	2.74E-8
164.5	-	3.25E-8
168.7	-	3.51E-8
170	11.9	3.85E-8

Chlorinated polypropylene

MIT Mech. Eng.

22% total chlorination on surface of pellets about 2 mm diam.,
compacted sample (#38-1)

18 MHz

T°C	κ'	κ''	σ	T°C	κ'	κ''	σ
20	2.58	.0245	2.45E-7	125	2.39	.0360	3.61E-7
35	2.62	.0252	2.52E-7	133	2.37	.0324	3.24E-7
49	2.62	.0351	3.51E-7	138	2.36	.0322	3.23E-7
63	2.60	.0414	4.15E-7	142	2.36	.0325	3.25E-7
79	2.55	.0440	4.41E-7	148	2.49	.0291	2.92E-7
92	2.49	.0428	4.29E-7	152	2.51	.0306	3.06E-7
100	2.47	.0421	4.22E-7	159	2.55	.0295	2.96E-7
115	2.40	.0376	3.76E-7				

For additional data on chlorinated polyolefins see Ph.D. Thesis of
Lewis Erwin, Mechanical Engineering Department, MIT, 1976.

"Teflon"-fused quartz laminate

Philco-Ford
(Lincoln Lab.)

8.515 GHz, 23°C

$$\kappa' = 2.35 \quad \tan \delta = .00052$$

"Ryton" R4, polyphenylene sulfide

Phillips Petroleum

8.515 GHz, 25°C

$$\kappa' = 4.01 \quad \tan \delta = .0052$$

"Tefzel," 20% glass reinforced

RCA

At 25°C

Freq., Hz	60	1E3	1E6	1E9	3E9	1E10
κ'	2.98	2.97	2.96	2.94	2.93	2.92
$\tan \delta$.0018	.0021	.0057	.0175	.016	.0142

15% TFE, polyphenylene sulfide

κ'	3.01	3.00	2.99	2.99	2.99	2.98
$\tan \delta$.00062	.00090	.00064	.0018	.00365	.0055

15% TFE, polysulfone

κ'	2.96	2.92	2.88	2.85	2.84	2.83
$\tan \delta$.0022	.0011	.0042	.0044	.0053	.0062

Solithane No. 1

Thiokol

1 GHz, 25°C

$$\kappa' = 2.632 \quad \tan \delta = .0244$$

Composition B

U.S. Army

915 MHz			2450 MHz		
T ^{OF}	κ'	$\tan \delta$	T ^{OF}	κ'	$\tan \delta$
80.8	2.832	.00273	81.5	2.779	.00191
84.8	2.829	.00298	84.7	2.781	.00218
89.2	2.830	.00363	88.6	2.780	.00251
97.1	2.831	.00408	97.0	2.781	.00296
109.5	2.833	.00496	109.5	2.784	.00357
121.3	2.834	.00563	121.5	2.783	.00426
133	2.836	.00640	133	2.780	.00491
146.7	2.841	.00740	146.8	2.784	.00601
158.2	2.855	.00895	158.9	2.791	.00744
159.4	2.857	.0092	159.5	2.806	.00788
160.8	2.868	.0097	159.5	2.808	.00805
161.9	2.871	.0098	160.6	2.848	.0084
167.2	2.915	.0131	161.9	2.855	.0088
170.2	2.945	.0153	164.2	2.864	.0095
170.2	2.948	.0158	166.7	2.871	.0107
170.2	2.949	.0162	167.2	2.875	.0108
170.2	2.951	.0167	170.2	2.905	.0143

Minol A

915 MHz			2450 MHz	
T ^{OF}	κ'	$\tan \delta$	κ'	$\tan \delta$
80.1	6.26	.0280	5.52	.0316
89.3	6.27	.0283	5.52	.0320
97.7	6.29	.0291	5.53	.0324
107.2	6.30	.0304	5.54	.0333
116.6	6.30	.0316	5.54	.0336
125.9	6.35	.0327	5.57	.0343
135.6	7.03	.0346	6.07	.0408
144.4	7.09	.0366	6.11	.0424
153.4	7.14	.0386	6.14	.0449
162.6	7.19	.0405	6.18	.0468
167.2	7.21	.0422	6.20	.0481
171.9	7.26	.0442	6.23	.0507
176.4	7.66	.0599	6.56	.0767
181.4	8.27	.107	~7.10	~.116

"Tritonal," H₂O contaminated, 915 MHz

T ^{OF}	κ'	$\tan \delta$	T ^{OF}	κ'	$\tan \delta$
77.6	5.51	.0355	146.3	5.28	.0551
83.4	5.51	.0370	155	5.30	.0570
91.4	5.48	.0390	159.7	5.36	.0582
101.4	5.46	.0407	163.8	5.45	.0606
110.3	5.43	.0433	131.7	5.33	.0524
119.1	5.38	.0464	110	5.29	.0461
128	5.33	.0481	89.7	5.26	.0399
135.9	5.29	.0511			

"Tritonal" at 2450 MHz

U.S. Army

T [°] F	κ'	tan δ	T [°] F	κ'	tan δ
82.3	4.99	.0175	155.6	5.04	.0313
91.3	4.97	.0187	161.4	5.05	.0317
100.4	4.97	.0194	164.6	5.05	.0332
109.7	4.96	.0204	168.6	5.06	.0335
118.7	4.95	.0218	173.5	5.09	.0356
123.4	4.94	.0225	177.8	4.16	.0544
127.8	4.95	.0239	177.8	4.03	.0569
132.4	4.94	.0242	180.1	2.65	.140
141.7	4.99	.0277	180.1	2.61	.148
151.2	5.01	.0297			

TNT, trinitrotoluene

U.S. Army

915 MHz			2450 MHz		
T [°] F	κ'	tan δ	T [°] F	κ'	tan δ
83.4	3.123	.00212	83.4	3.102	.00183
97	3.127	.00282	97	3.104	.00214
107.5	3.132	.00316	107.5	3.108	.00234
120.4	3.135	.00360	120.4	3.111	.00253
129.3	3.137	.00366	129.3	3.112	.00272
138.6	3.140	.00400	138.6	3.113	.00295
145.1	3.141	.00449	145.1	3.112	.00328
152.2	3.142	.00523	152.2	3.115	.00376
156.8	3.150	.00597	156.8	3.123	.00443
161.4	3.157	.00736	161.4	3.125	.00496
163.8	3.168	.00919	163.8	3.130	.00697
166.4	3.181	.0117	166.4	3.137	.00898
169	3.209	.0172	169	3.153	.0128
170.8	3.231	.0214	170.8	3.167	.0165
173.6	3.319	.0374	173.6	3.204	.0218
178.4	3.645	.0937	173.6	3.210	.0255
180.6	3.677	.0973	173.6	3.221	.0296
			178.4	3.370	.0639
			180.6	3.382	.0709

U.C. 8950-24-3

Union Carbide
(Whittaker)

24 GHz

		κ'	tan δ
22 [°] C	Ambient	3.145	.0083
24 [°] C	Wet	3.26	.0165

Ferro/Kerimid 581 Astroquartz

Whittaker

26% resin wt., 1.8% voids

Measured at 8.5 GHz, water soaked, after 24-hour boil

T [°] F	κ'	tan δ	T [°] F	κ'	tan δ
73	3.627	.0093	400	3.587	.0078
206	3.661	.0087	500	3.532	.00764
300	3.650	.0083			

Ferro/Kerimid E glass

26% resin wt. .3% voids

Whittaker

Measured at 8.5 GHz, water soaked after 24 hour boil

T°F	κ'	$\tan \delta$	T°F	κ'	$\tan \delta$
64	5.145	.0107	398	5.195	.0112
200	5.212	.0109	499	5.242	.0106
300	5.218	.0109			

Hexcel F-178/E glass

Whittaker

42% resin wt., 2% voids

Measured at 8.5 GHz, water soaked after 24-hour boil

T°F	κ'	$\tan \delta$	T°F	κ'	$\tan \delta$
73	4.454	.0150	400	4.524	.0218
200	4.504	.0167	498	4.323	.0214
300	4.512	.0185			

Hexcel F178/Astroquartz 581

Whittaker

34.4 to 37.4% resin wt., 0.6 to 1.6% voids

T°F	κ'	$\tan \delta$	T°F	κ'	$\tan \delta$
75	3.572	.0148	400	3.558	.0210
199	3.622	.0167	500	3.441	.0222
261	3.601	.0165	75	3.385	.0064
310	3.533	.0190			

Experimental Pl/Quartz

Whittaker

Brunswick-BP1 373581 Astroquartz

Measured water soaked after 24-hour boil

8.5 GHz			24 GHz		
T°F	κ'	$\tan \delta$	T°F	κ'	$\tan \delta$
71	4.498	.0714	73	3.86	.0924
200	4.491	.0330	147	4.09	.0725
300	3.835	.0228	248	3.65	.0228
5 min., 300	3.740	.02005	345	3.42	.0087
400	3.341	.0133	432	3.37	.0118
500	3.237	.02216	500	3.36	.0130
75	3.349	.0040	73	3.35	.0045

PD 753/Astroquartz A 172

Whittaker

24 GHz, dry

T°F	κ'	$\tan \delta$	T°F	κ'	$\tan \delta$
23	3.16	.00227	177	3.205	.00242
66	3.17	.00258	221	3.213	.00261
121	3.19	.00295	260	3.23	.00292

PD 753/Astroquartz A172

Whittaker

24 GHz, water soaked after 24-hour boil

T [°] F	κ'	tan δ	T [°] F	κ'	tan δ
73	3.093	.01154	428	2.92	.0037
163	3.08	.0048	502	2.96	.0033
250	3.04	.0047	79	3.07	.0027
351	2.99	.0053			

Skybond 710/Astroquartz 581

Whittaker

21% resin wt., 9.4% voids

8.5 GHz, water soaked after 24-hour boil

T [°] F	κ'	tan δ	T [°] F	κ'	tan δ
69	8.83	.2097	300	3.190	.0248
200	7.219	.0573	398	3.035	.0070
200, 1 min.	7.152	.0638	500	2.909	.0072
200, 2 min.	6.972	.0632	76	3.151	.0024

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